Figure 1. Drawing Table. See page 37.

ELEMENTARY COURSE

IN

MECHANICAL DRAWING

FOR

MANUAL TRAINING AND TECHNICAL SCHOOLS

COMPRISING

Selection and Use of Instruments; Geometrical Problems; Orthographic Projections; and, Shades and Shadows

WITH CHAPTERS ON

MACHINE SKETCHING AND THE BLUE PRINTING PROCESS

BY

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PREFACE

The course of drawing outlined in the following pages is the result of several years' experience in placing the subject before manual high school pupils, and is designed to be a text book for individual use.

In view of the fact that while all of the pupils of a manual high school are required to study the subject of mechanical drawing, but few of them will follow drafting or engineering as a vocation, the author has endeavored to present the subject in such a way as to make it of the greatest value in training the mind and developing the reasoning power and the imagination.

"The value of drawing as a means of mental discipline is believed to be not inferior to that of any of the studies at present included in the curriculum of the public schools." (Isaac Edward Clark, A. M.)

In order to accomplish the desired end the following points have received consideration:

1st. The endeavor has been made to present all work in a style as free as possible from confusing technical language and intricate mathematical methods. It will be found in practice that the workman often obtains desired results by more direct methods than does the theorist, and that while employing the same principles he applies them in simpler ways.

2nd. No plate showing a finished sheet of geometrical or projection problems required in this course has been included. This prevents copying which is of little value beyond affording a chance to acquire a good technical style.

3rd. Exercises designed solely for the acquirement of facility in the use of instruments have been omitted. Skillful handling of the tools is easily gained in other work, and the time so saved can be made to yield much more valuable returns.

4th. Geometrical drawing is used as an introduction to the course for several reasons. It is the foundation of all drawing either for industrial or for artistic purposes. It involves the consideration and representation of only two dimensions, is therefore simpler than orthographic representation, which involves three dimensions, is more easily comprehended by the pupil, and is in every way an appropriate stepping stone. Again, few pupils are competent either through natural fitness or previous

training to appreciate the exactness required in instrumental construction drawing or to reason in logical order from given premises to the proper conclusion. For both these ends geometrical drawing affords a satisfactory medium. It is assumed that the pupil has no knowledge of geometrical drawing. If the contrary is the fact, these problems may be omitted if it seems desirable.

5th. Only such geometrical problems have been included as are of a fundamental nature and capable of the broadest application. These have been arranged in order of regular and consequent development to bring the pupil as quickly as possible into the proper condition of mind for the satisfactory consideration of the more difficult subject of orthographic representation.

The scores of geometrical problems, either variations of those here given or depending directly upon them, have been eliminated, as were all exercises on the use of tools, because they are not valuable enough in comparison with other possibilities of a school course to be retained.

6th. In introducing the subject of orthographic projection the pupil is called upon first to deal with the concrete instead of the abstract. That is, the pupil is required to first consider and picture in space the solid which is a fact rather than the point, line, and plane, which are ideas and not perceptible to the hand or eye. This treatment although contrary to the method employed in descriptive geometry, upon which the science of orthographic representation is founded, is believed to concur with the principles of psychology.

7th. Models of the object to be represented and of the planes on which the representations are made, are used for the first few problems. From the study of these the pupil learns the fundamental methods of conventional orthographic projection. From the finished projections he studies the representations of the abstract point, line, and plane, and forms rules in regard to these representations.

8th. Models are dispensed with as soon as possible. After a little practice and when the methods of orthographic representation have been acquired, a pupil will read a model and picture in his mind its different views almost as readily as he would read a drawing.

Obviously this is not good training for the imagination and is not conducive to original work on objects or constructions which have never existed. Therefore models are not used through a large part of the course.

9th. Exact specifications are given for each problem. The chief office of mechanical drawing is to present an idea so completely that the construction shown may be exactly produced. An architect, engineer or designer is constantly required to conceive and represent something which never existed and his work is necessarily based upon specifications and requirements more or less exact.

10th. The problems in projection are arranged to give a regular development of principles and in nearly every problem some new principle is introduced. In this way past work is constantly reviewed, new work is introduced gradually, and no single feature is given an undue amount of time.

11th. The pupil is taught what the layout of a sheet of drawing is and how to make it, but in nearly every problem the layout is directly given. This has been done because the sheets are of fixed and rather limited size and the dimensions prescribed for the objects have all been made as large as possible to afford clearness in the drawing. Marginal spaces are very small and the layout must be more carefully planned than would be necessary in even professional work.

12th. The method of representation used conforms to the best modern practice. That is, the third angle of projection is used and the object is shown in each instance as viewed from a position adjacent to the side shown. Hence if the pupil adopts drafting as a profession he will not have to unlearn what he has acquired in this course.

13th. The applications to practical work of principles evolved in theoretical work have been shown in certain problems. While for some reasons it would be desirable to use this plan in connection with other problems it is usually found better to reserve such applications for a later and special course because they involve much technical instruction on subjects outside the bounds of mechanical drawing.

ARTHUR W. CHASE.

CHICAGO, September, 1904.

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MECHANICAL DRAWING

KINDS OF DRAWING.

Drawing is the delineation of form. It may be divided into three classes, Representative, Constructive, and Decorative.

Representative Drawing is that which treats of objects as they appear. Figure 2 shows a representative drawing of a glove box.

Constructive Drawing is that which shows how objects are to be made. Figure 3 shows a constructive drawing of the same glove box.

Decorative Drawing is that which treats of ornamenting objects. Figure 4 shows an example of decorative drawing to be used on a book cover.

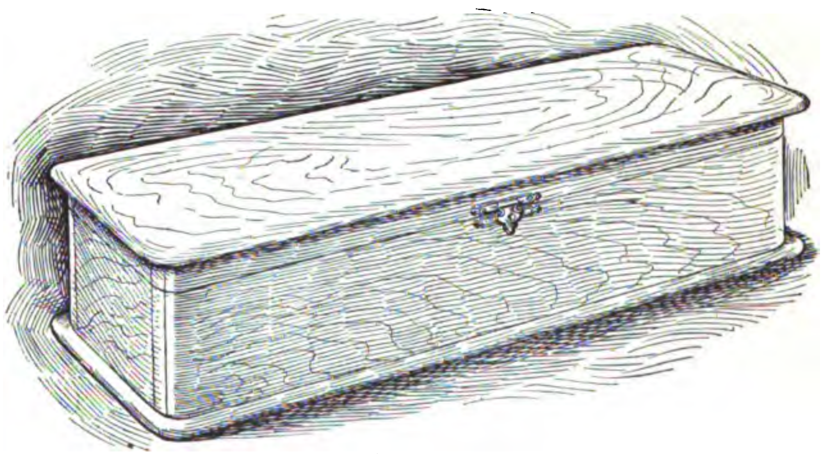


Figure 2.

Representative drawing is almost always rendered in freehand. Decorative drawing is usually free-

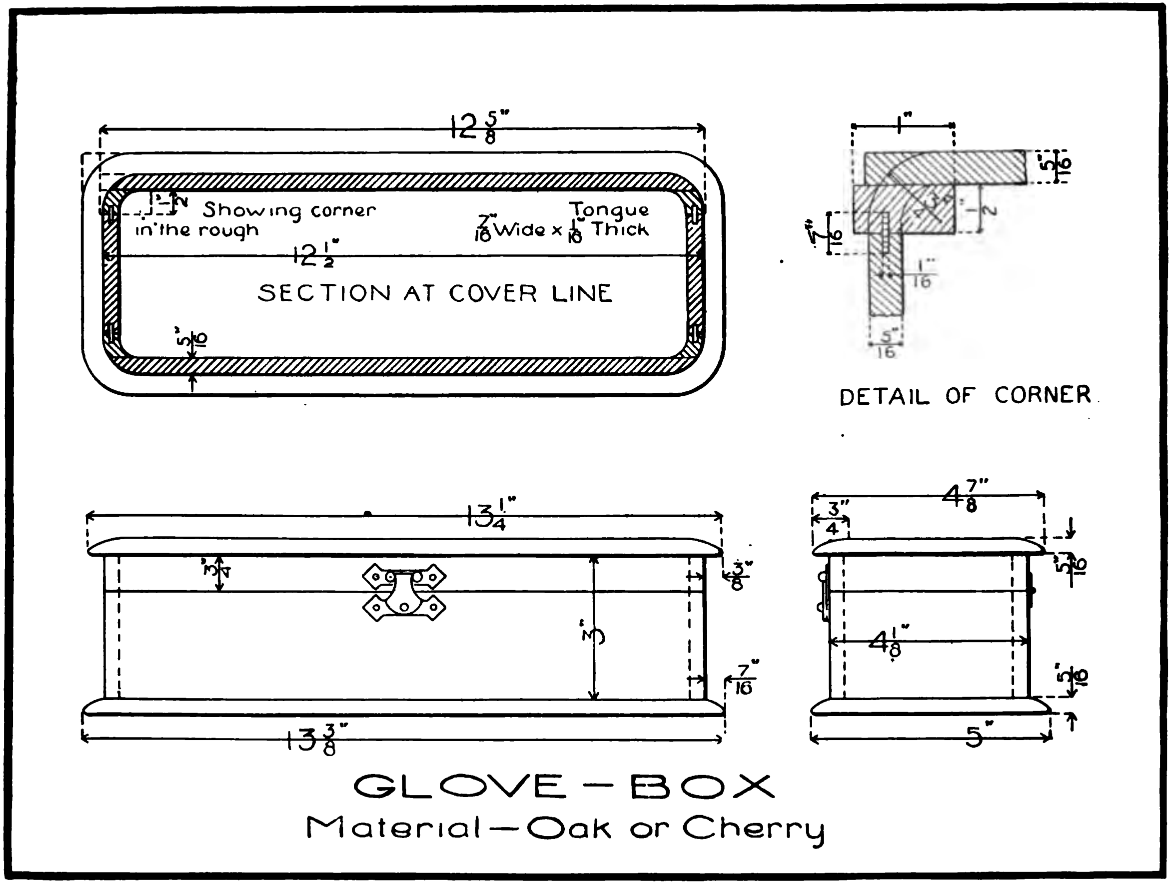

12 5/8"
Showing corner in the rough
Tongue 7/16" Wide x 1/16" Thick
12 1/2"
SECTION AT COVER LINE
DETAIL OF CORNER
13 1/4"
13 3/8"
4 7/8"
4 1/8"
5"
GLOVE-BOX
Material—Oak or Cherry

Figure 3.

hand but occasionally mechanical. Constructive drawing is almost entirely mechanical—so nearly so that it is usually designated Mechanical Drawing.

Mechanical Drawing is so called because it is executed by the use of tools. All constructive drawing is usually termed mechanical drawing whether it is done freehand or with tools, because it follows the general methods of mechanical drawing. Frequently the term mechanical drawing is used with the limited meaning of machine drafting.

Geometrical drawing, architectural drawing and engineering drawing are wholly or largely mechanical, but are ordinarily distinguished by the special names given.

Figure 4.

SELECTION OF DRAWING TOOLS.

In selecting tools for mechanical drawing the items of kind, number, size and cost should receive attention.

A case with instruments in place is shown in Figure 5.

Such a case is usually made of wood covered with leather and lined with velveteen, and the instruments lie in suitably shaped pockets. This arrangement affords a safe and convenient way of keeping the instruments and, moreover, shows at a glance whether any one of them is missing.

Figure 5.

A "case of instruments," as is shown by trade catalogues, may comprise a small selection of poor tools valued as low as $1.00 or a large selection of fine tools valued as high as $200.00. The following list gives a statement of the smallest assortment of tools and materials adequate for carrying on satisfactorily the work outlined in this course. The selection named will be found sufficient for advanced work also, and comprises nearly everything that a professional draftsman needs. The quality specified is the cheapest that is worth buying and if well cared for the instruments will do good work for years.

LIST OF DRAWING TOOLS.

1 set of drawing instruments in case, comprising the following .... $ 5.00

1 pair 5 in. German silver compasses, with fixed needle point leg, pen leg, and lengthening bar.

1 pair $4\frac{3}{4}$ in. German silver hair spring dividers.

1 $3\frac{1}{2}$ in. spring bow pencil, German silver handle with conical top.

1 $3\frac{1}{2}$ in. spring bow pen, German silver handle with conical top.

1 3½ in. spring bow dividers, German silver handle with conical top.
1 5¼ in. right line pen with black wooden handle.
1 5 in. right line pen with red wooden handle.
1 4 in. German silver protractor, divided to degrees.
1 3 in. x 5 in. x 67½ degrees hard rubber lettering triangle.
1 box or tube of 4-H leads for compasses.
Needles for compasses and bow instruments should be shouldered on each end.
1 20 in. x 27 in. drawing board of special design with pigeon hole and rubber buffers...$ .90
1 27 in. pear wood T square.............. .25
1 8 in. 45 degrees hard rubber triangle...... .25
1 10 in. 30 x 60 degrees hard rubber triangle. .25
1 irregular curve of hard rubber and special design .... .30
1 12 in. flat scale with celluloid faces; one face divided to sixteenths, and the other to scales of one-fourth inch, and three inches to the foot .... .80
12 ⅜ in. riveted brass head thumb tacks, best quality .... .05
1 Hardmuth's 2-H hexagon drawing pencil... .10
1 Dixon's No. 2 "Cabinet" pencil............ .05
1 1¼ in. x 4½ in. sandpaper pencil sharpener .05
1 Tower No. 30 Multiplex pencil eraser....... .10
1 1 in. x 1¼ in. x 3/16 in. Faber ink eraser... .05
1 ¾ oz. bottle Higgins' black water proof drawing ink .... .25
1 ¾ oz. bottle Higgins' carmine water proof drawing ink .... .25
1 Eagle Pencil Co.'s No. 3, or E. Faber's No. 269 penholder .... .05
6 Esterbrook's No. 621, or Gillott's No. 404 writing pens .... .05
1 5 in. x 5 in. chamois skin penwiper....... .05
25 10 in. x 13½ in. sheets Napoleon drawing paper punched for binding .... .50
1 10 in. x 13½ in. sheet drawing paper ruled for lettering .... .05
1 5 in. x 6¼ in. 12 sheet block of paper ruled for lettering .... .15
1 10½ in. x 14 in. portfolio for drawings..... .35
1 No. 64 Lakeside note book................ .10
1 6 in. x. 9 in. 30 sheet block of 40 lb. ledger paper .. .. .05

$10.00

DESCRIPTIONS OF DRAWING TOOLS.

COMPASSES.

Compasses and other all-metal instruments should be selected with extreme care because of their great variety in shape and quality. The different grades may be ranked from best to poorest as follows: American, best; Swiss; German; English; and lastly, French, the poorest.

American manufacturers now provide very fine goods which excel those of foreign make in quality of material, finish of workmanship, and beauty and propriety of design. The best grade pivot-joint instruments of domestic or foreign manufacture, carried by all first-class dealers, are recommended for all professional men but are usually too costly for school use. Therefore the list here given designates German-made instruments of first or second quality.

English instruments are of poor design and but little used nowadays. The French instruments are mostly brass, and should not be purchased, for like most cheap things, they usually prove very unsatisfactory.

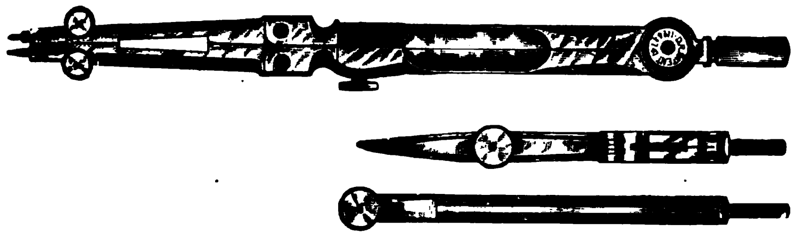


Figure 6.

The steel employed in the manufacture of very cheap instruments is of so poor a grade that it is scarcely better than iron; and in consequence neither holds its shape nor wears well. It is desirable, therefore, to select instruments of medium grade or better, which shall be of German silver and a

good quality of steel. A medium size of compasses —about 5 inch—answers well for general use. A desirable form is shown in the illustration Figure 6. The joint is arranged for adjustment with a small wrench or key, in order that the movement may be made more or less free. The legs should readily remain at any desired position, and should, when opening or closing, move uniformly if under a steady pressure, any irregularity of movement indicating an imperfect joint. One of the legs of the compasses, that carrying the needle point, should be fixed, and the other, carrying ordinarily the pencil lead, should be removable.

The pencil leg can be replaced by the pen leg or lengthening bar, the latter being used to increase the length of the pencil or pen leg in drawing circles of considerable radius.

The stems of these different legs should fit accurately in their proper sockets in order that there may be no uncertain and undesirable side-play.

It must be borne in mind that the tools here described are hand-finished, and the parts of different tools, as, for instance, separate pairs of compasses, are not interchangeable.

A very good test in selecting compasses, though a severe one, is to insert the lengthening-bar and pencil-point, open the compasses to their greatest extent, and strike a circle. Reverse the movement and redraw the circle. If only one line appears and that no broader than the one first drawn, the compasses are well made. Great care should be taken, however, to swing the compasses with a light and uniform pressure, else the legs will be sprung and justice will not be done to the instruments. In order that the needle, pencil, and pen points may always be perpendicular to the surface of the paper, a joint is made in each leg. These joints should also move smoothly but a little less freely than the joint in the head of the compasses.

The needle leg carries a needle, so-called, that may be easily replaced if lost or injured, and that has a shoulder which prevents the point from sinking into the paper and board beyond a certain slight depth.

The needle may also be pushed in or out and fastened at any desired point, thereby making the leg of the compasses a trifle shorter or longer. In order to avoid unnecessary annoyance take care to select instruments in which the pencil point or the pen point may be replaced, the one by the other, without making any change in the length or position of the needle. Having been once adjusted the needle should answer in that position equally well for either point. The pencil point is made at the present time to hold cylindrical leads designed for this and similar purposes, and the arrangement will be found far preferable to the old style which accommodates a small pencil having the wood on it.

The socket for the lead should hold the lead firmly without any wedging by means of paper or

bits of wood, and in a similar way the socket for the needle should be drilled of such a size that the needle, while easily moved, fits closely enough to have no lateral movement. The pen usually has its outside blade hinged, as shown in the cut, Figure 6, in order that it may be readily cleaned or sharpened.

See that the joint is of good construction, allowing the blade to swing freely but without any side motion. The inner blade of the pen should be nearly straight, and the outer one somewhat curved. When the nibs of the pen are in contact, the space between the blades at a point ¾ in. from the nibs, should be about 3/32 in. wide. If the distance is much less the ink will dry too rapidly, and if much more the ink will gather in a large body near the nibs, and will have a tendency to run very easily or be jarred out, forming a blot.

The nibs should be broad rather than pointed in order to retain the ink well.

HAIR-SPRING DIVIDERS.

The Hair-Spring Dividers, see Figure 7, resemble the compasses in general form but are intended for laying off equal distances, and for transferring distances from one part of the drawing to another. They are composed of steel points set into German silver shanks which latter are hinged together. The joint should work smoothly, the legs come quite together, and the points be sharp and equal in length. A pair of 4¾ in. dividers will be found satisfactory in size.

One leg of the dividers is furnished with an adjustable spring controlled by a thumb-nut. By this contrivance from which the instrument receives in part its name, the point of the leg may be moved a hair's breadth after the coarse or approximate setting of the dividers has been made.

Figure 7.

SPRING BOW INSTRUMENTS.

The spring bow dividers, pencil, and pen, Figures 8, 9 and 10, are designed for laying out lines and distances of small dimensions and will be found very convenient. They should be separate and distinct instruments in order to ensure convenience and accuracy. Spring bow instruments with interchangeable legs will be found unsatisfactory because of the very limited action of the spring.

A convenient size is that known as the 3½ in. in which the legs, from point to crotch, are about two

and one-half inches long, the balance of the instrument being handle.

The legs should be of one piece of steel, into which the handle screws. In the old style instruments the legs are separate pieces fastened to the shank by screws, but this arrangement is undesirable because the parts are liable to become loosened, thereby destroying the accuracy of the instrument.

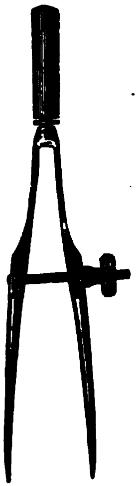


Figure 8.

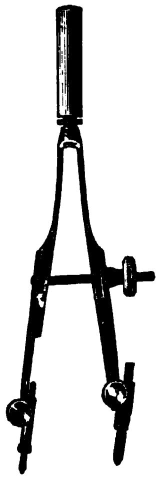


Figure 9.

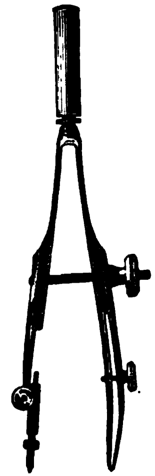


Figure 10.

The handle should be of German silver, cylindrical in form, finely milled to give a firm hold, and with a conical top to act as a pivot. Bone or ivory handles are more easily broken than metal ones.

The spring of the legs should be such that when the legs are opened to the full extent allowed by the adjusting screw, a circumference may be drawn which shall be clear, smooth, and free from any irregularities due to the weakness with which the legs are held in position.

The spring bow dividers, called also spacing dividers, or steppers, have merely two cylindrical legs with very sharp points. In good instruments these points come accurately together when the legs are closed. **The spring bow pencil** has one leg provided with a socket and set-screw to hold a needle, and the other with a split-socket and a clamp-screw, similar to the pencil point of the large dividers.

The latter socket should have drilled in it a hole of such size as to hold closely even when not clamped, an ordinary instrument lead. When selecting a bow pencil, subject it to a test similar to that for the larger compasses. Insert the needle and a pencil sharpened to a conical point. Close the legs of the instrument and notice whether the points come exactly together which they should do in order to draw very small circles.

The spring bow pen is very similar to the bow pencil, the chief difference being fully explained by its name.

The blades of pens of this size are not hinged. In choosing this instrument close the legs and adjust the needle so that it extends a hair's breadth beyond the pen-nibs. Open the legs to half the limit

of their movement and the pen-nibs to about 1/32 in. and apply the instrument to paper.

In this position the nibs of the pen should each touch the paper, showing that under average conditions, the pen will draw a smooth line. It will be noticed that, unlike the legs of the large compasses, those of the spring bows have no joints in them allowing the lower portion to be kept perpendicular to the paper.

The blades of the pen should be perpendicular in their width to a line joining the nibs and needle point, and when the legs are brought together the needle should strike just at the midle of the width of the blades.

The adjusting screws of spring bow instruments should not be exceedingly fine, and the nuts upon them to withstand wear satisfactorily should not be less than 3/16 in. long.

RIGHT LINE PENS.

The Right Line Pen, Drawing Pen, or **Ruling Pen,** as it is variously called, is shown in Figure 11. It consists of two steel blades attached to a handle of ivory or wood, the latter being by far the better as it is not as easily broken. For general work where more than one color of ink is used, at least two pens will be needed. This arises from the fact that it is quite difficult to so completely clean a pen of black ink as to prevent discoloration of the lighter ink which is used subsequently. The annoying task of frequent thorough cleaning is avoided then, by having two pens, a 5½ in. and a 5 in., the larger of which shall have a black handle and be kept exclusively for black ink, while the smaller has a red handle and is for colored ink alone. The

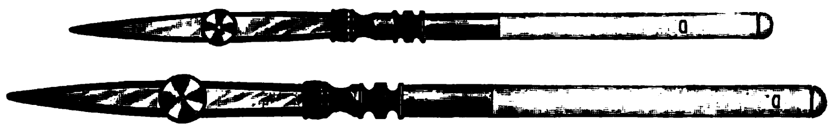


Figure 11.

different colored handles serve to distinguish the pens readily. Drawing pens with German silver blades for use with colored ink can also be bought. They do not rust as do the steel ones, but neither do they wear as well. The blades of drawing pens are made either from a solid piece or of two pieces hinged together. If the hinge is well made the blades seldom become loose and sometimes the independent blades prove the more convenient in cleaning or sharpening the pen. The blades of the right line pen, unlike those of the circle pen, that

is the pen belonging to the compasses, have an equal curvature, but when the nibs are in contact, the space between the blades at a point ¾ in. from the nibs, should be as in the circle pen, about 3/32 in. and for the same reason—that the pen may hold such a quantity of ink as shall not flow too readily, nor dry up too quickly.

This dimension varies a trifle, of course, with the size of the pen, but a fair average is given. A defect common in right line pens is that the nibs are too pointed. They should, instead, be rather broad in order to retain the ink satisfactorily. Broad nibs ground to a thin edge will make as fine a line as is necessary.

The curvature of the inner blade carries the nibs of the pen away from the straightedge against which the pen is used, thus preventing the ink from adhering to the straightedge from which it would flow onto the paper and form an unsightly blot.

The blades should be of good material and properly tempered in order that they may have spring enough to hold their positions, and be hard enough to withstand the very considerable wear to which they are subjected. The spring of the blades should held them open 3/64 in. with a force sufficient to ensure a line of even width under light pressure against the straightedge. The distance between the blades of the pen is regulated by an adjusting screw so that either fine or coarse lines may be made as desired. The butt of the blades is frequently bored out to form a sheath for a pin made upon the end of the socket into which the handle is set.

This pin is called a pricker and is used in duplicating a drawing by placing finished work upon the blank sheet and transferring the dimensions by pricking through at the desired points.

The method is to be condemned both from its inaccuracy and because of the more or less unsightly holes which are made in both sheets. If a pricker is thought necessary, a better one can be made out of an ordinary sewing needle set into a bit of wood for a handle. The sewing needle is highly polished and can be more easily pushed through the paper, and such a size can be selected as shall not make too large holes in the paper.

PROTRACTOR.

The Protractor is a circle scale, and is therefore divided into degrees and fractions of a degree. A

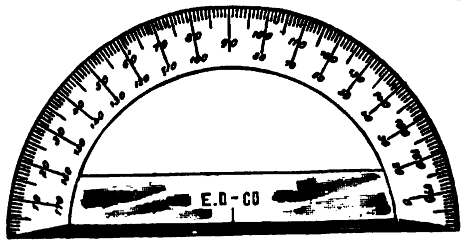


Figure 12.

protractor may be rectangular, circular or semi-circular in form, the last named being the ordinary and most approved. See Figure 12.

The rectangular protractors are made of boxwood or ivory, and the circular ones of paper, horn, brass or German silver. Most protractors have their edges beveled in order that the divisions may be carried close to the drawing paper and dimensions transferred with as small a chance of error as possible. Each form of protractor has a straightedge upon which the centre of the circle is marked in such a way as to be readily applied to the point at which it is wished to lay off or read an angle. A semicircular protractor is to be preferred for ordinary work and one of 4 in. diameter will be found accurate enough for common work.

Civil engineers in doing fine work frequently use protractors of 8 in. diameter with radial arms extending several inches beyond the circumference.

The Box for Leads found in the case of instruments contains leads for the compasses and bow-pencil. The leads contained in this box as it comes from the manufacturers are often of too soft grade and poor quality to be of any use. Satisfactory leads can be purchased from dealers in drafting supplies.

They should be one or two grades harder than that in the drawing pencil.

The Needles for Compasses should be shouldered on both ends. As usually furnished by the manufacturers they are tapered on one end, presumably that the compasses may be used as dividers. Such use of the compasses is inconvenient, and unnecessary where there is a regular pair of dividers in the set as in this outfit. A beginner is very apt to carelessly use the tapered point when he should use the shouldered point in drawing circles, thereby leaving large and unsightly holes in his drawing. If each end of the needle is shouldered he cannot make this error.

DRAWING BOARD.

The drawing board for school use should be 20 in. by 27 in. in size, as that will accommodate either elementary or advanced work. The material should

Figure 13.

be ½ in. first quality clear soft pine, free of pitch and thoroughly kiln-dried. Fiddle-timber should be used, that is, boards in which the lines showing the yearly growth, run as nearly as possible at right angles to the surface. Boards which show these markings running nearly parallel with the face will shrink and swell with the ordinary changes of the weather in a most annoying manner.

The drawing board should be made of five 4 in.

by 27 in. strips glued together and further held by two cleats on the back side to prevent warping.

Each cleat should be made of 7/8 in. x 2 in. x 19 5/8 in. hardwood, placed three inches from the end of the board and dovetailed into it so that the board as it shrinks or swells may move along the cleats and yet maintain a flat surface.

Across the cleats and flush with one end of them should be fastened a board 1/4 in. thick by 11 1/2 in. wide. At the back edge of this board, that is, towards the center of the drawing board, should be fastened a strip filling the space from cleat to cleat and from back board to drawing board.

The pocket thus formed affords a convenient receptacle for the remainder of the outfit in transporting from place to place.

At distances of one inch from the ends of the cleats should be placed small rubber plugs for buffers to prevent noise and to keep the drawing board from marring the desk or table on which the board is placed.

These buffers should be fastened by being put into holes and glued in place. If fastened by means of nails or screws they will do more injury to the desk than would the board without buffers.

The edges of the board should be dressed true, and it is convenient to have them at right angles but they need not be exactly so, as it is not good practice to use the T-square from more than one edge of the board for the same drawing.

T-SQUARE.

The T-Square should be nearly or quite long enough to draw the longest line that can be made upon the drawing board.

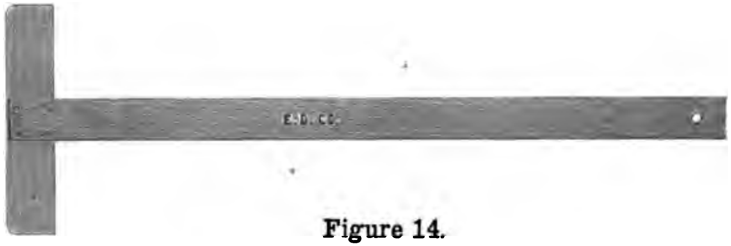


Figure 14.

On a 20 in. by 27 in. board it is advisable to use a T-square not less than 30 inches long, and certainly not less than 27 inches—the length of the board.

A T-square is measured by the length of the blade outside the head. The longer of the pieces composing the T-square is called **the blade,** and the

shorter, **the head.** For a T-square 30 inches long the blade should be $2\frac{1}{4}$ in. wide and 3/32 in. thick, and the head $\frac{3}{8}$ in. x 12 in. The material may be all pearwood, or all cherry, or maple blade and black walnut head, or generally speaking, any kind of firm, close-grained wood.

For ordinary work the head should be single, and fixed, that is, made of one piece and fastened permanently to the blade. See Figure 14. Let the blade be glued and screwed directly upon the face of the head, in order that the triangles may readily slip over the head when working near the left edge of the board. The head should have its upper inside corner chamfered or rabbeted, in order that the guiding edge of the head may be trued up, should it for any reason get out of proper shape. It is not necessary to have the upper edge of the blade absolutely at right angles to the head, though desirable to have it nearly so, since all lines perpendicular to the T-square should be drawn with triangles.

A more elaborate form of T-square is that shown in Figure 15, in which the head is double and one side swivels in order to draw parallel lines other than horizontal. The movable head is fastened in any desired position by clamping it firmly with the thumbscrew provided for that purpose.

Figure 15.

TRIANGLES OR SET-SQUARES.

Triangles, sometimes called **set-squares,** are made preferably of hard rubber or transparent celluloid. These materials hold shape better than does wood, and present very smooth edges along which the pencil or pen glides readily.

The principal forms of triangles are shown in Figures 16, 17 and 18. The one shown in Figure 16 is called a **forty-five triangle,** and has two angles of 45 degrees, and one of 90 degrees. The one next shown, Figure 17, is called a **thirty-by-sixty** triangle, and the magnitudes of its angles are 30 degrees, 60 degrees, and 90 degrees, respectively.

The size of a triangle is determined by the size of one of the sides including the right angle. On a thirty-by-sixty triangle the larger side, and on a forty-five either side since they are equal in length.

To use with a 20 in. x 27 in. board an 8 in. forty-five triangle, and a 10 in. thirty-by-sixty should be chosen.

A forty-five triangle and a thirty-by-sixty are supposed to constitute a pair when they are of such proportions that they have their longest sides of very nearly equal length.


Figure 16.


Figure 17.


Figure 18.

Since a triangle is used largely to draw lines perpendicular to others, it is important that its largest angle should be exactly 90 degrees. To test this place the vertex of the largest angle at a given point on a straightedge laid on the drawing board, with the shortest side of the triangle in contact with the straight edge. Then draw a line along the other side of the triangle. Reverse the triangle so that it shall lie in the opposite direction but with the vertex still at the same point and the triangle against the T-square, and again draw a line. The result should be a single line. If two lines appear, the space between them is equal to twice the amount in which the triangle is in error.

The remaining triangle shown, Figure 18, comes in the box of instruments and is called a **lettering triangle.** Its chief angle is $67\frac{1}{2}$ degrees. The use of this triangle is indicated by its name.

IRREGULAR CURVE OR SCROLL.

Irregular curves, sometimes called **scrolls,** are also preferably made of hard rubber.

They are manufactured in many different shapes.

One of medium size and having a large variety of curves will be found very useful. The one shown

Figure 19.

in Figure 19 probably combines as many desirable curves as any does. The size to be chosen depends largely upon the character of the work in hand. To correspond with the rest of the equipment as here given, the curve should be about 3½ in. x 8 in., outside dimensions.

SCALE.

The scale is commonly made of wood, paper, or metal, and may be either flat with beveled edges, as shown in Figure 20, or triangular as shown in Figure 21, the former being preferred.

Ivory scales were formerly quite common, but they are not desirable because they are costly and easily broken. Paper scales are too easily destroyed to be placed in inexperienced hands.

Metal scales are trying to the eyes because the marks upon them do not show very plainly.

Wooden scales, with white celluloid faces upon which the divisions appear in black, are light, cleanly, easily read, and generally satisfactory.

The flat form will be found preferable to the triangular because it bears a far less number of scales and is therefore not nearly as confusing.

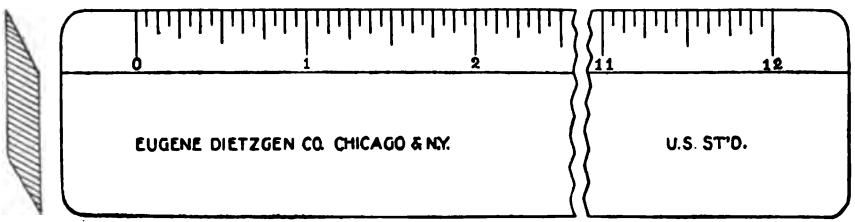


Figure 20.

The ordinary length of the scale is 12 in., not counting the small portion at each end, which is

not divided, but whose use is to protect the end divisions from injury.

Architects' scales, used also by mechanical engineers, are divided along one edge to 16ths of an inch, and along the other edges to scales of 1/4 in., 1/2 in., 1 in., 3 in., etc., to the foot.

Chain scales are used by civil engineers and are divided into 10ths, 20ths, 40ths, 50ths, etc., of an inch.

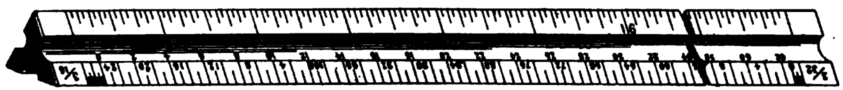


Figure 21.

THUMB-TACKS.

Thumb-tacks usually consist of small German-silver or brass disks having pointed pins inserted in their centres, as shown in Figure 22.

The disks—called the heads—should have thin edges in order that the T-square may readily slide over them. The pins should be screwed into the heads and also riveted. In the cheaper grades of thumb-tacks the pins are only forced in and are very liable to be pushed through when being used and to inflict ugly wounds on the thumb.

One-piece stamped steel tacks, shown in Figure 23, are also to be had, and in the smaller sizes are found to answer fairly well. In this kind of tack the point is merely a portion punched from the head. These steel tacks are cheaper, but the points break off easily and frequently remain in the board where they form serious and undesirable obstacles to the plane whenever it is desired to refinish the face of the drawing board.

The size of a thumb-tack is determined by the diameter of its head; 3/8 in. tacks will be found to hold the drawing paper sufficiently well for temporary work. Larger tacks usually have thicker heads, therefore offer more obstruction to the T-square. Also they have larger pins and are in consequence placed or removed with greater difficulty.

Figure 22.

Figure 23.

Copper or iron tacks of 1 oz. size, such as are to be found in most hardware stores, are used in some drafting rooms, in place of thumb-tacks, but are not as desirable for school use.

PENCILS.

The pencil used in mechanical drawing should have a lead of fine and even texture. A good pencil will last for a long time, therefore the best is not expensive. The hexagon-shaped pencil is to be preferred for it is less liable than the round, to roll from the table and break the lead. The Hardmuth's Kohinoor, or the Faber's Siberian leads, sustain high reputations for uniform excellence.

Leads are made of different degrees of hardness and each pencil has its grade indicated by letters or figures at one end.

For brown paper an H or H H (called 1 H or 2 H) pencil is preferred because it makes a rather black mark which may be easily erased, while for ordinary work on white paper of hard surface a 2 H should be chosen. For very fine work, or that which will not be inked for a considerable time, a 5 H may be used to advantage, as it keeps its point better and the lines made by it are not so easily erased. For general work such as calculating and taking notes, a medium soft pencil of cheaper grade like Dixon's No. 2 Cabinet, may be used.

Leads for compasses are cylindrical in form and are not covered with wood.

PENCIL POINTER.

Pencil pointers are of many different forms, ranging from a simple piece of sand paper to a quite complicated machine. Some draftsmen use a flat file. For school use, a sand paper block from which the leaves can be detached as fast as worn out, will be found the most satisfactory. See Figure 24.

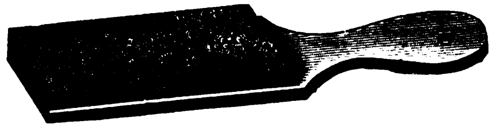


Figure 24.

A pencil sharpener may be readily made by gluing a bit of No. 0 sandpaper upon a small, flat stick.

PENCIL ERASER.

The Pencil Eraser should be of soft, fine-grained white rubber, free from grit and showing no tendency to glaze or to smirch the paper. A medium size should be chosen and it is well to have a piece with one end blunt while the other end is brought to an edge for erasing in limited spaces.

Figure 25.

Tower's Multiplex eraser, shown in Figure 25, made of alternate layers of solid and sponge rubber, will be found very satisfactory.

INK ERASER.

Ink erasers are made in two general forms—steel scratchers, and rubbers having fine pumice stone incorporated in them. The latter form, shown in Figure 26, should be chosen as the steel erasers are extremely harsh in their action on the paper and are certain to spoil its surface unless most skillfully used.

The sand-rubber, as it is frequently called, leaves

Figure 26.

the surface of the paper in good condition to again receive ink, and with it, if carefully used, ink may be removed even from tracing cloth and tracing paper. The best kind of ink eraser is the small size (about 1 in. x 1¼ in. x 3/16 in.) made by A. W. Faber.

ERASING SHIELD.

An Erasing Shield is a piece of thin, flexible metal provided with slots and holes of various shapes and sizes. Celluloid or even paper may be used for a shield, but metal is more desirable. The shield permits erasures limited in size to that of the opening,

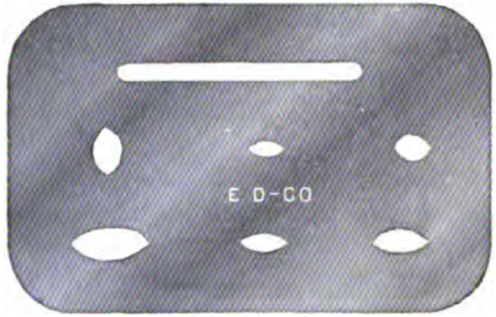


Figure 27.

to be made on a drawing without damage to the remainder of the drawing by placing an opening of the shield over the part to be erased and rubbing through the hole.

DRAWING INK.

Black Drawing Ink is to be had either in solid form, see Figure 28, or in liquid form, see Figure 29. As using is the only sure test of the quality, it is well to buy from some reliable dealer and trust to him to furnish a good article. If it is wished to

experiment with ink, the following points may receive attention in its selection.

Good stick India ink usually has a marked odor

Figure 28.

of musk, and when broken presents a bright, very slightly golden lustre. When slightly wetted it has

Figure 29.

a pasty feel, and when rubbed up, remains well diffused through the water. Solid ink or stick ink, as it is usually called, is now very generally superseded by the ready-prepared liquid ink, which is moderate in price, and always in condition to use. Each bottle is conveniently furnished with a quill in the cork which affords a means for inserting the ink between the nibs of the drawing pen. Liquid drawing ink is produced by several American manufacturers. That made by C. M. Higgins & Co. is quite black, flows freely and does not thicken or deposit coloring matter as does the stick ink. The waterproof kind, which withstands a considerable amount of washing when doing tint work, is generally preferred and used.

Red Drawing Ink, as generally used, is in the ready prepared liquid form. Moist water color—carmine—mixed with water may sometimes be used to advantage, as it can be easily erased from drawing if any change is desired, by touching it with a fine brush dipped in a weak solution of chloride of lime. The liquid red ink cannot be so removed, but a sand-rubber must be used in order to erase it.

Red drawing ink may be had in either carmine or scarlet tint according to the taste of the user. It is made by all manufacturers of black drawing ink.

PEN HOLDER.

The Pen Holder may be of the ordinary kind. It is well to select one of rather large diameter so that

it shall not cramp the hand. A holder with a metal socket for the pen should be avoided as it is slippery and the pen cannot be well controlled. A cedar stock with a hard rubber socket is to be preferred.

WRITING PENS.

Writing Pens should be selected in accordance with the work in hand. Esterbrook's No. 621, or Gillott's No. 404, will be found excellent for lettering and figuring. For fine work a Gillott's No. 303 may be used.

PENWIPER.

The Penwiper should be a piece of chamois skin. This material is effective and is the best to use because it leaves no lint on the pen nibs.

DRAWING PAPER.

Drawing Paper is put upon the market in two general forms—in sheets and in rolls. Select the former because the paper will lie close to the drawing board whereas that from a roll will curl and interfere with the movements of the T-square and triangles.

Drawing paper is either hand or machine made. It is graded as to surface, as Hot Pressed (H. P.) which has a smooth surface and is used mostly for fine line drawings; Cold Pressed (C. P.), which has a finely grained surface and is used for general drawings and water-work color; and Rough (R), which has a coarsely grained surface and is used for very bold drawing and sketching.

For mechanical drawings not to be colored—which is almost invariably the case, aside from topographical work—a white, heavy-weight, hot-pressed paper of medium smooth-grained surface, will be found the best. To obtain a heavy-weight paper in small sizes it should be cut from large sheets as the thickness of paper varies with the size of the sheet, the largest sheets being the heaviest in any one quality of paper. Such paper as just recommended cannot always be obtained in sheets and when found the sizes may not be satisfactory, in which case the purchaser must accept the roll paper. In this form the paper may be had in widths varying from 27 to 62 inches, each roll containing from 10 to 100 yards. If paper is bought from the roll it is well to have it cut from the outside of a large roll in order to have as little curl in it as possible.

A good way is to have cut a quantity of sheets sufficient to last a considerable time. They should be put in a press or placed under a heavy weight for several days, and when put by for gradual consumption, should be laid with the concave side down in order that the paper by its own weight may take out some of the curl. If the paper is used from the roll instead of being cut up, it is a good idea to

rewind the roll in such a way as to bring inside that surface which was previously outside. Then when the paper is fastened to the drawing board, the paper curls away from the board at its centre instead of at its edges, and less interference with the movements of the T-square will be experienced. The inner surface of paper rolled as it comes from the factory is generally the better finished and is considered the right side.

Sheet paper is usually water marked, and that side from which the mark reads correctly, is the right side.

Having found a paper whose appearance is satisfactory, proceed to test its qualities with pencil and ink erasers. Good paper should be of such close, firm texture that lead and ink lines remain largely on the surface. Rub the lines vigorously with a close-grained pencil eraser, and a Faber's ink eraser. The marks should be readily erased, leaving the surface of the paper with no woolliness and differing but little in appearance, however held to the light, from the original finish. Such a condition tends to the concealment of the results of carelessness or lack of skill. Moreover it shows that the paper will readily bear ink again, and that the ink when applied will not exhibit an inclination to creep or spread.

The size of sheets into which the paper should be cut is a matter of choice depending upon the kind of work to be done.

As it is easier to work at the extreme right and left hand edges of a sheet rather than to bend far over to get at the top of it, the paper should be cut of an oblong rather than a square shape. Sheets that are cut 10 in. x 13½ in. will be found of convenient size and shape for school work. Each sheet should be punched with two holes near the left edge in order that the drawings may be fastened for preservation in a portfolio made for the purpose.

DETAIL PAPER.

Detail Paper. For many purposes it will be found that brown drawing paper answers equally as well as white, at the same time being less expensive. Brown drawing paper is commonly known as detail paper because it is largely used for drafting in full size the details of some construction which has previously been drawn as a whole to some small scale. Manila paper of smoothly finished surface was long used as detail paper, but it withstood erasures very poorly and has been superseded by papers of firmer texture having slightly pebbled or grained surfaces.

TRACING CLOTH.

Tracing Cloth is used in producing copies of drawings with a view to saving the originals. It is also found very valuable in reproducing drawings by various photographic processes of which blueprinting is the most common. Tracing cloth, as its name indicates, is thin cloth rendered transparent,

and prepared for tracing by a coat of sizing. Two varieties are common, one designed to take ink on either side, therefore having each side highly finished, the other having a dull finish on one side which will receive pencil marks or water-colors, while the opposite side is finished as in the previous case, for ink. There is no objection to buying tracing cloth or paper by the roll, as it is so flexible that it can readily be spread flat upon the drawing.

Tracing cloth can be had in widths varying from 30 in. to 54 in. and is usually put up in rolls of 24 yards each.

TRACING PAPER.

Tracing Paper is designed for the same purpose as tracing cloth, and where it is to be put only to temporary use it may be found preferable because it is cheaper than the cloth. Tracing paper is to be had in two general qualities known as natural paper, and prepared paper. The natural is well described by its name and should be chosen because it is generally tougher, works better, and does not deteriorate as fast as the prepared. The preparations used in making paper artificially transparent render its surface greasy so that ink does not flow smoothly upon it, and they also seem to rot the paper so that it soon becomes brittle and breaks readily. Tracing paper may be had in sheets and in rolls of various sizes and qualities.

BLUE-PRINT PAPER.

Blue-print Paper is employed for the photographic reproduction of drawings from tracings. It may be prepared or purchased, but those who use only a small quantity generally prefer to buy it from the dealers. Further explanation of this subject will be given under the head of Blue Printing.

LETTERING PAPER.

The Sheet of Lettering Paper should correspond in quality and size with the regular drawing paper. It is intended for a drill in lettering, introductory to the course in drawing. It is well to have this sheet furnished to the pupil ready ruled, because a beginner finds great difficulty in doing the ruling with sufficient accuracy. The sheet should be printed from a wax plate engraving. The lines should be printed parallel and horizontal, and should cover a 9 in. x 12 in. space, beginning ½ in. from the right edge of the sheet and leaving equal spaces—about ½ in.—at the upper and lower edges of the sheet. The lines are to be spaced as follows, beginning with the upper line: 1/16 in., 1/8 in., 1/8 in., 1/16 in., 1/8 in., 1/8 in., etc. The lines should be printed very lightly in blue-gray to imitate as closely as possible a fine pencil line such as would be put upon a drawing in doing this kind of work.

MONTHLY LETTERING PAPER.

The Block of Lettering Paper is intended for the regular monthly exercise in lettering. It should be made from the same kind of paper which is employed for the drawing so that the pupil may grow accustomed to the surface and obtain similar results in each case. This block should comprise 12 sheets, one for each school month with a few more for emergencies. Each sheet should present a 4½ in. x 6 in. space for lettering. The block may be made from large lettering sheets, cut into four equal parts and properly glued together.

PORTFOLIO.

The Portfolio for mechanical drawings, called also a binder, should be made of pasteboard covered with cloth. It should be a trifle larger than the drawings—10½ in. x 14 in. will do very well—and should be provided with two holes near the back, protected by eyelets, through which two short, soft, flat shoestrings may be passed to hold the drawings in place. A similar hole near the opposite end of the covers and also provided with a string allows the drawings and covers to be held securely together.

NOTE BOOK.

The Note Book should be made of paper of such quality that it will take pencil or ink nicely. It should be of convenient size—about 5 in. x 8 in. will do very well—and for class work all notebooks should be uniform for the convenience of the inspector in handling a large number.

BLANK PAPER.

The Block of Blank Paper is intended for general figuring and for trying the pen upon before applying it to the drawing. The paper composing the block should, therefore, be of good quality and suitable for ink, but need not be a drawing paper.

Figure 30.

BEAM COMPASSES.

The Beam Compasses are often not included in a draftsman's individual set, but every well ap-

pointed drafting-room has at least one pair for general use by the members of the drafting corps.

Beam compasses are designed for drawing circles larger than those that can be made with the ordinary 5 in. compasses. They consist of two German-silver box-shaped sockets, see Figure 30, made so as to slide easily upon a wooden beam or bar, and to which they can be fastened in place by set screws provided for the purpose. Each socket has a smaller socket into which can be set a divider point, pencil point, or pen point as desired.

One of the box sockets is also provided with an adjusting screw by which the accompanying point may alone be moved slightly and set exactly, after the approximate setting has been made.

SECTION LINER.

Broken or cut surfaces are frequently shown on working drawings by parallel lines disposed in various ways to show different parts or different materials. See Figure 32, also Figure 64.

These parallel lines may be made with T-square and triangle, or with two triangles, placed together, the spacing being determined by the eye alone, or a special tool called a **section-liner** may be used to regulate the spacing.

Section liners of various forms may be bought at the stores which carry draftsmen's supplies. Most of these section liners are intricate and costly, and but few of them are satisfactory. Because of this and since little section lining is done now-a-days a draftsman seldom buys a section liner, but makes a simple one if the ordinary tools are found insufficient.

A cheap and tolerably efficient section liner is illustrated in Figure 31.

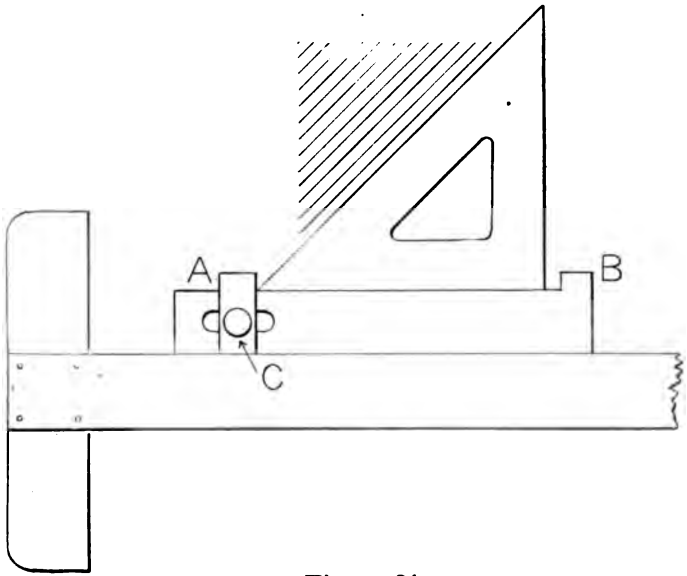


Figure 31.

It consists of a piece of wood about $\frac{1}{8}$ in. thick, with a projection at one end which acts as a stop for the triangle. Near the other end of the main piece is a second piece which acts as a stop at that end. This second stop is adjustable and is held in place

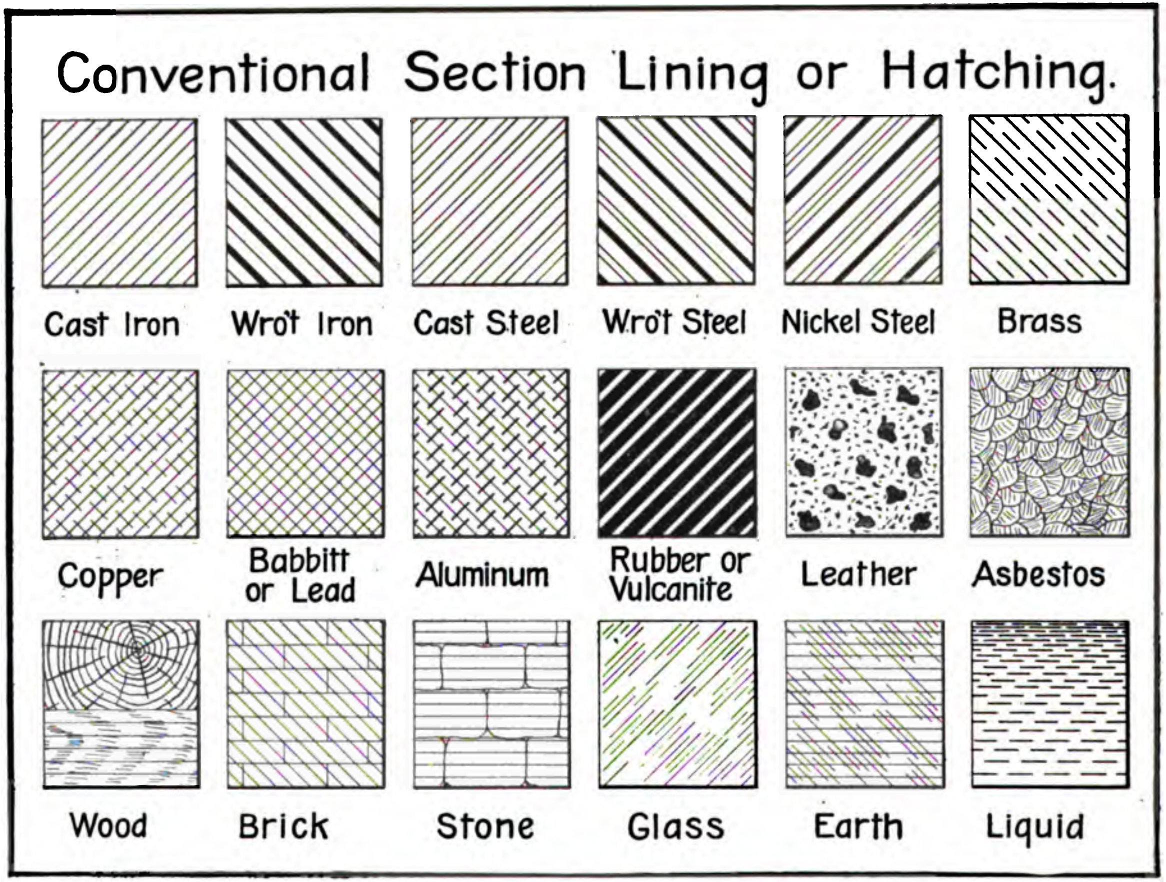

Conventional Section Lining or Hatching.
Cast Iron
Wro't Iron
Cast Steel
Wro't Steel
Nickel Steel
Brass
Copper
Babbitt or Lead
Aluminum
Rubber or Vulcanite
Leather
Asbestos
Wood
Brick
Stone
Glass
Earth
Liquid

Figure 32.

by means of a clamp thumb-screw passing through both pieces and movable at will along a slot in the main piece.

SECTION PAPER.

Section paper is a thin paper ruled with heavy lines into 1 in. squares and by lighter lines into 1/4 in. or 1/8 in. squares as the case may be. See Figure 33.

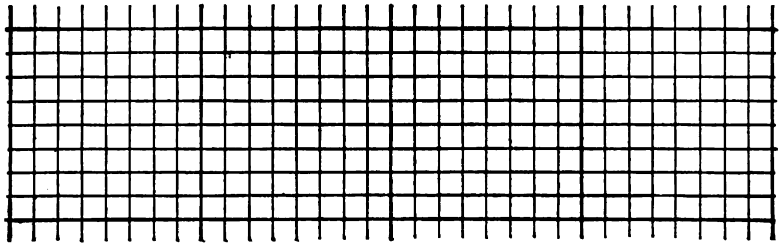


Figure 33.

It is used chiefly in mechanical drawing for making free hand sketches and it enables the draftsman to rapidly make drawings which closely approximate the desired sizes and shapes without the use of a scale. In some shops all the drawings are made on section paper and its users claim that it saves much time.

Section paper need not be obtained as a part of a beginner's outfit, for it is not usual to employ it on elementary work.

WATER COLORS.

Water colors may be obtained in the form of hard cakes, or of thick paste in small porcelain pans, or of thin paste in collapsible tubes. The cakes are objectionable because too much time is required to obtain from them any considerable amount of color. Morover small parts of the cakes are apt to break off and, if not thoroughly rubbed up and dissolved—as is often the case—produce blotches when the color is being laid.

The colors in tubes are apt to harden, in which case they cannot be expelled from the tubes by pressure as is intended. Also the caps to the tubes frequently get gummed in place by the colors and are sometimes removed with much difficulty.

For school purposes the moist colors in "half-pans" are the most satisfactory. A box of moist water colors is shown in Figure 34.

The colors made by Winsor & Newton of London, Eng., are considered the standard and are always of good quality.

At the present time water colors of very good grade are made in America also.

The colors should be selected for mechanical drawing according to the following list, which gives the names of the colors and the purposes for which they are used in the conventional representation of materials:

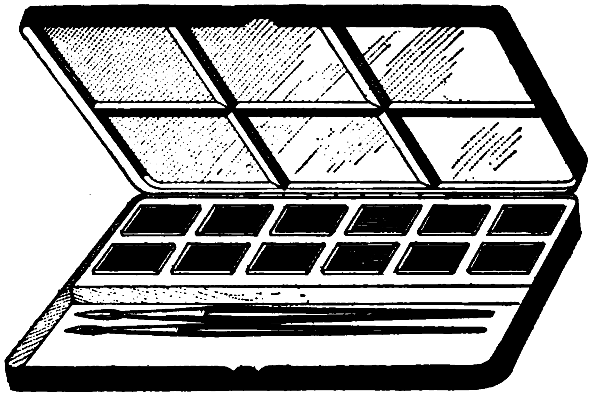


Figure 34.

1. Burnt Sienna ....Wood
2. Burnt Umber ....Earth
3. Carmine....... with Prussian Blue ...Steel; with Gamboge ......Copper
4. Gamboge ....Brass
5. Light Red ....Brick
6. Payne's Gray ....Cast Iron
7. Prussian Blue ....Wrought Iron
8. Sepia, ...with Yellow Ochre. ....Stone
9. Yellow Ochre,...... with Sepia ....Stone
10. Vermilion.
11. Chinese white. (In tube.)
12. India ink. (In stick form.)

Chinese white is useful for wholly covering lines or spots which could only be erased with great difficulty or perhaps not at all.

Frequent occasion will be found for it in making drawings to be reproduced by photographic processes.

The India ink to be used in this connection should be perfectly black and of the best quality.

The colors should be kept in a japanned tin box made for such purpose and arranged to be used as a palette also. The box keeps dust and dirt from the colors and preserves them from drying out rapidly.

WATER COLOR BRUSHES.

The best **water color brushes** are made from the black or red sable. Inferior and less expensive brushes are made of camel's hair.

Black sable brushes are quite too expensive for

school use. The red sable will be found firm and elastic and are recommended.

The camel's hair brushes are generally unsatisfactory because of their want of elasticity though the best grades are acceptable.

Water color brushes are at present usually made with metal ferrules and wooden handles and ordinary sizes run from No. 1, the smallest, to No. 12. They are made single-ended or double-ended as shown in Figure 35. Three single-ended brushes—

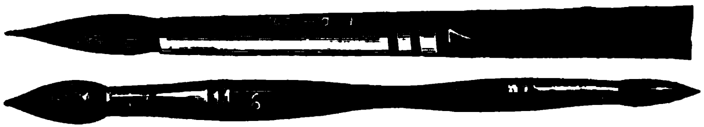


Figure 35.

small, medium, and large—Nos. 5, 8 and 11, or two double-ended brushes of similar sizes, should be obtained.

To determine whether a brush is good or otherwise, dip it in water till thoroughly wet, and then throw the water from it by a quick motion. The brush should assume a gently convex shape, should come to a fine point, and should preserve its elasticity while still wet.

A flat sable brush about 2 in. wide will frequently be found useful for applying large washes or for dampening paper.

Some small saucers and some small glasses will also be required to hold washes or clear water. They may be obtained where colors are on sale or butter-plates, small sauce dishes, and small tumblers may be made to answer the purpose.

DRAWING TABLE.

The drawing table, shown in Figure 1, the frontispiece, was designed by the author especially for school work. It is made of quarter sawed oak and in cabinet style.

It is planned to give the greatest amount of accommodation with the least consumption of space and has proved satisfactory both in completeness and convenience. Each table is furnished with six drawers—one for each period of a six-hour school day. Each drawer is large enough to hold the entire outfit of drawing tools and materials, including drawing board, of one pupil. This arrangement avoids the confusion that would arise if the class were compelled to remove the boards from a rack on entering the drafting room and replace them on leaving. It also gives complete protection to the drawings and to the drawing tools of which each pupil should possess his own individual set.

Each drawer is furnished with a permutation lock of which only the user and the teacher know the combination. Each table is numbered and each drawer lettered.

The general dimensions of each table are as follows: Body, 25 in. front to rear, by 36½ in. long;

top, $32\frac{1}{2}$ in. front to rear, by $40\frac{1}{2}$ in. long; height of top, 32 in. at front, and 35 in. at rear. The tables are all made of the same height and then arranged in groups of three different heights. The additional heights are secured by the use of false bases which raise the tables $3\frac{7}{8}$ in. and $7\frac{3}{4}$ in., respectively.

The drawers measure inside $22\frac{1}{4}$ in. from front to rear, by 31 in. long by $3\frac{3}{8}$ in. deep. In each table the drawers are separated by partitions which prevent any pupil from getting at the contents of the drawer next below his.

The ink bottles are held in a bracket, made specially for the purpose, which is stationed on the right hand end of the desk near the front, but is not shown in the cut.

In this position the bottles are within convenient reach of the draftsman and yet are not in his way nor can they interfere with any sized drawing board that he may desire to place upon the desk. Moreover, with the bottles in the location described, the draftsman is not so apt to drop ink upon his drawing while filling his pen as he would be if the bottles were stationed upon the top of the desk.

The top of the bracket is covered with a brass plate through which the necks of the bottles protrude. This plate prevents the bottles from being upset or broken and allows that any ink which may be dropped upon the bracket may be easily wiped off.

CARE AND USE OF DRAWING TOOLS.

Good tools having been obtained, they should be carefully kept both to preserve the tools and as a desirable drill in order and neatness.

Good work cannot be done even with good tools unless they are kept in proper condition. Handle the instruments carefully, wipe them nicely before laying them away, and they will last for a lifetime.

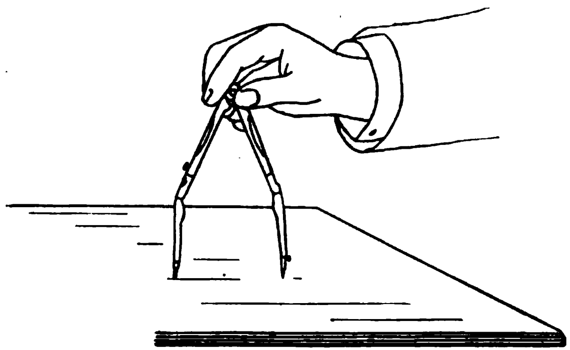


Figure 36.

Compasses and other instruments of that class should be carefully kept in a case of some soft material. Light wooden boxes lined with plush, such as are commonly found holding sets carried in stock by the dealers in drawing tools, make very good cases.

The joint in the head of the compasses should be well adjusted by means of the wrench furnished with the instruments for that purpose. If too tightly clamped, it will be found tiresome to move the compasses, and they will wear unnecessarily. If clamped too loosely they will not hold their position. Compasses are used in striking arcs and circles.

The pencil-point may be prepared for use by inserting a small piece of lead sharpened to a flat or chisel-shaped edge, and so placed that the width of the point shall be in line with the travel of the leg.

The needle-point and pencil-point should be of the same length when the instrument is closed. The legs of the compasses should always be so adjusted that the points shall be at right angles to the surface of the paper, see Figure 36.

This avoids making a conical-shaped hole with the needle point, and brings the nibs of the pen when using ink squarely upon the surface of the paper. In striking a circle, the compasses should be used in one hand, held very nearly erect, and swept with a continuous movement from left to right, beginning towards the edge of the paper next the

draftsman. It takes some skill to successfully conceal the point of union of the circle, especially when pressure is applied to the compasses in more than one direction. The lengthening bar is used for increasing the length of one leg of the compasses in order that circles of larger radius may be drawn. It is inserted in the same way as one of the points and has itself a socket to receive the point which it displaces. The pen belonging to the compasses is very similar to the drawing or right-line pen, therefore the explanations concerning the sharpening of the latter, and which appear below, are equally applicable to the former. Great pains should always be taken to wipe the pen before laying it down.

The Hair-Spring-Dividers should be handled delicately in order that their adjustment shall not be disturbed. The joint should work properly and the legs should be maintained of equal length. It is very easy to push the leg in a little too far and then bend it over, thereby breaking off the point. Holes made in the surface of the drawing paper in laying off distances with the dividers should be so very small as to be almost invisible.

The Spring-bow Instruments will readily suggest the uses for which they are intended.

Owing to the constant pressure of the springs in these instruments there is a comparatively heavy wear upon the nuts and screws. This may be in great measure avoided, by pinching the legs of the instruments towards each other with the left hand while the nuts are traversed along the screws by running over them the forefinger of the right. This will also be found a very quick way of setting the instruments roughly. The fine adjustments may then be made in the ordinary manner.

When laying off a distance several times in succession with the dividers, reverse the movement of the instrument at each step. This will be found much easier than to turn the dividers constantly in one direction. Let the pressure upon the dividers be very light in order that the paper may not be marred by having holes punched in it.

The Drawing Pen is designed for use in drawing lines with ink. It is employed chiefly for straight lines, but is also used in drawing with the irregular curve or scroll.

Ink should be introduced between the nibs of the pen if the ready-prepared drawing ink is used, by means of the quill set in the cork of the bottle for that purpose.

The pen is regulated to make the desired width of line by means of the screw connecting the blades.

The drawing pen should be held in the hand in much the same manner as a writing pen, except that it should be vertical instead of inclining backwards. Almost vertical would be more nearly correct, as it will be found necessary to incline the pen a trifle to the right in order that it may run smoothly. To hold the pen as directed it should be grasped between the thumb and first two fingers crossing the

middle joint of the forefinger and the end of the second finger.

The tips of the third and fourth fingers should be used as supports upon which the hand may glide, see Figure 37. In this way the greatest freedom of movement may be secured, and a line several feet long may be inked at one sweep.

In using the pen, the head of the adjusting screw should be turned away from the straightedge, and

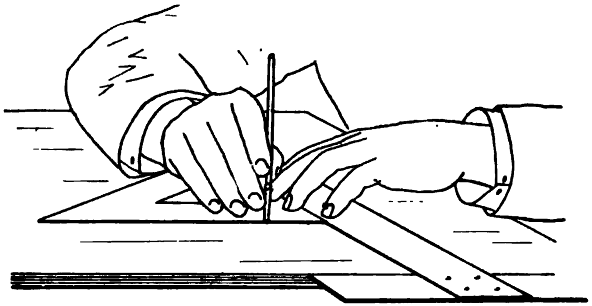


Figure 37.

the pen carried with a steady movement from left to right. Owing to the curvature of the blades, the pen nibs will not touch the straightedge if the pen is carried properly erect. Should the top of the pen be inclined outwards the nibs will then be thrown in against the straightedge, under which the ink will be drawn, and a bad blot will result.

Let the pressure against the straightedge be light and even. Heavy or uneven pressure will close the pen thus making the line unsightly because of its varying width. Occasionally the ink may refuse to flow readily from the pen because it has dried a little between the nibs. In such case the pen may be wiped, or should it be very desirable not to release the T-square or triangle from its position, the nibs may be pressed together upon a finger of the left hand, or upon a piece of paper which should always be kept at hand.

Upon closing the nibs the partially dried ink will be pressed out and the remaining ink will again flow freely.

It is well for the novice to always try his pen upon a bit of paper before beginning to ink a drawing, in order that he may see what width of line his pen will make and whether it is working well or not. In doing this the pen must be held and used as it will be on the drawing.

Form the habit of always wiping the pen before laying it down. It is better to sacrifice a little ink than to continually have the pen in poor condition. A piece of chamois-skin or wash leather makes an excellent pen-wiper.

Sharpening the drawing pen. It will be found that the action of paper upon the drawing pen is sufficiently harsh to in time change the shape of the nibs so they will not work nicely. The trouble can be remedied by re-sharpening the pen, for which a small, flat-faced, medium-grained Arkansas oil-stone will be found necessary. Screw the pen-nibs

together, and draw them over the stone at the same time swinging the handle of the pen in a vertical plane parallel to the faces of the blades. In this way the points should be shaped to look like the end of a sharp ellipse, see Figure 38, which is the most

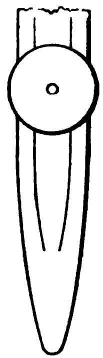


Figure 38.

approved form for general work. The nibs should then be ground on the outsides with a slightly rolling motion, the pen handle being inclined about 20 degrees to the face of the stone, see Figure 39.

The nibs should, of course, be brought to an equal thinness of edge. A small magnifying glass will be found convenient to inspect the progress of the work. Next the screw should be removed from the pen, the blades swung wide open and their inside surfaces applied flatly to the stone. This is not for the purpose of grinding to a new shape, but merely to remove any burr which may have been turned inside from the previous grinding. A few strokes on a piece of leather or drawing paper may help to give a finish to the grinding. The nibs should not be brought to a knife edge, as in that condition they would cut the paper.

Should they be too sharp their condition may be improved by a light application to the stone, the pen having the nibs screwed together and being held as in the first position. But the ends of the nibs must not be too thick else the pen will not make a fine line. A trial on paper will determine whether the pen is in a satisfactory condition.

The Protractor is usually numbered both from

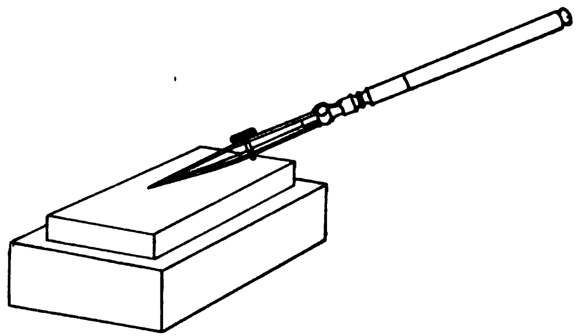


Figure 39.

right to left, and the reverse. The center of its circle is indicated by a point at the middle of its diameter. When it is required to lay off a certain angle, place the center of the protractor at the point

where the required vertex is to be, with the straight edge extending along the line already drawn to form one side of the angle. With the pencil make a point at the circumference of the protractor opposite the desired number of degrees or half-degrees. Should any smaller measurement be desired it may be judged by the eye, except in very fine topographical work for which special protractors are made.

Removing the protractor, connect the point just made with the point indicating the vertex, and the desired angle appears.

The Drawing Board should have its edges straight and its top a plane surface.

As wood, especially when not protected, is readily influenced by atmospheric changes, it may occasionally be found necessary to plane the top of the board or to true up its edges. The condition of the board can be ascertained by the application of a straight-edge which should, under proper conditions, touch throughout its length. Should the surface of the board be convex or quite rough, the high points will catch and retain the dust and lead pencil dirt gathered by the T-square and triangles in their movements over the paper. If the board has a hollow or concave surface, or is badly dented, it will be difficult to avoid pushing the needle point of the compasses or the legs of the dividers through the paper, thereby making large and unsightly holes. It is not necessary to have the edges of the board absolutely at right angles. They should, however, be straight because the head of the T-square will pivot or rock on any high point, thus throwing a series of lines out of parallel with each other.

Drawing-boards, especially those having drawings on them, should be put away out of the dust, and where the drawings will not be liable to injury. A convenient way is to slide them into a closet having cleats on its sides which will support the boards.

In class rooms the drawing tables should be furnished with drawers, each one of which is of such dimensions that it will accommodate the board, tools, and entire drawing outfit of one pupil. The number of drawers in the desk should equal the number of pupils who use the desk during the day.

The T-Square, when not in use, should be hung up by the hole in the blade or laid in a drawer on top of the drawing board, in order that it may retain its shape. Where many T-squares are used in common it is well to have them numbered since they frequently vary enough from each other not to be interchangeable. A drawing begun with a certain T-square should be finished with the same one. Occasionally the head of the T-square should be tested to see if it is perfectly straight. The square will rock on a high place on its head quite as readily as on a high spot on the edge of the drawing board.

If the upper edge of the head is chamfered or rabbeted, a skillful mechanic can true the head without removing it from the blade. A line drawn

from left to right on the board is usually considered as a horizontal line, and it is only to draw such that the T-square is used alone. Exception is of course made to those instances in which the square is placed and used merely as a straightedge. In ordinary use the head of the T-square is grasped in the left hand and pressed against the left edge of the drawing board. It may then be placed at any desired position by sliding it back and forth. In making the line place the pencil or pen at the point nearest the head of the square and draw from left to right along the upper or further edge of the blade. It is not considered good practice to draw on either side of the blade indiscriminately.

Occasionally it may be found necessary to use the lower edge, but this should not be done without applying it to a long line already drawn to ascertain whether they are parallel.

To remove the square from the board it should be raised by the head.

Never remove paper stretched upon the board (the process of stretching paper will be explained later), by using the edge of the T-square as a straightedge along which to cut, as such practice is in the majority of cases ruinous to the square.

Triangles may be hung up or laid away in a drawer. The wooden ones as they come from the manufacturers are not protected against atmospheric changes, and it is almost impossible to keep them from warping. Doubtless a good coat of shellac would prove beneficial to them. The rubber triangles are much more satisfactory. Either kind is somewhat fragile and should be handled carefully. Triangles are used to draw lines perpendicularly to the T-square, or those making with it any angle which is a multiple of 15 degrees. They may also be used together to draw parallel or perpendicular lines, and with the square to draw geometrical figures of certain shapes. It is not well to use the triangles against the lower edge of the T-square for the same reason that it is not well to draw lines along that edge. A line perpendicular to the blade of a T-square in the usual position of the square, is regarded as a vertical line, and is drawn by placing one side of the triangle against the blade and sliding the triangle along till the other side passes through the desired point. In this position the right angle of the triangle should be at the left, and the line should be drawn from left to right, that is, away from the blade.

The Lettering Triangle is used principally to give the slope of italic letters. It is not designed to give the slant of the inclined lines found in letters like A, K, M, N, V, W, etc. The positions of the inclined lines in the letters named and in other similar letters are to be determined by the eye.

The Irregular Curve should receive the same care as the triangles. It is used to draw any curves other than parts of a circle—notably, ellipses. This is done by locating the points through which the

curved line is to pass and then applying the edge of the curve so that it shall coincide with as many points as possible. So apply the scroll to the points that the outline of the instrument curves similarly to the desired line. That is, while passing along the points from a curve of smaller radius to one of larger, do **not** apply the scroll so that in following its form the pencil travels along from a curve of larger radius to one of smaller radius. Having drawn a portion of the curve the scroll is shifted to a new position and the operation repeated. It is best not to attempt to draw too many points at one setting of the curve as the resulting line will present a broken appearance. A skillful draftsman will draw very complicated curves and yet have them perfectly smooth.

Should it be desired to draw the reverse of any curve, the proper points may be marked on the edge of the scroll, which is then placed on the board with the opposite side up from that first used and the curve then drawn between the points marked. The irregular curve should not be used where the shape has to be repeated exactly by the workman, if the curve can possibly be put in with the compasses. Mechanical drawings are intended largely for the use of pattern-makers, blacksmiths and similar workmen who, in copying the forms pictured, are not supplied with irregular curves but have to rely upon compasses.

The Scale requires only that it shall receive careful handling in order that the edges may not be marred or broken. It is sometimes found desirable to keep fine scales that are not used constantly, in little cases made of stiff paper and having the ends open, into which the scales just slide.

A scale is necessary in order to make a drawing in its proper proportions. When an object is drawn of the same size as that in which it exists, or is to exist, it is said to be drawn "Full size." It is obvious, however, that such a course is impossible in map work or drawings of large structures. Therefore recourse is had to the plan of dividing three inches, one and a half inches, one inch, and other distances (instead of one foot), into twelve parts, each of which parts is regarded, subdivided, and used as an inch. Thus if the space of three inches is called a foot and divided into twelve parts, one of these parts (one-quarter of an inch, in fact), will be called an inch, and will be found to be only one-fourth as large as the size it is used to represent. Nevertheless if the same scale is used on all parts of the drawing the just proportions are preserved and may be easily read by applying the same scale. The scale of three inches to the foot is called "Quarter size," since it bears that relation to the dimensions which it represents. Drawings are made in "Half-size" by using the ordinary full size scale and calculating the different measurements. The 12 in. flat scale, designed for this outfit of tools, has one edge divided into inches and

sixteenths for full size drawings. The other edge is laid off in scales of 3 in. to the foot, and $1\frac{1}{2}$ in. to the foot for quarter size and eighth size drawings, respectively.

There are eleven different scales on the edges of a triangular architects' scale.

For map-work chain scales are used, having the inch divided into 10ths, 20ths, 30ths, 40ths, 50ths and 60ths or 80ths.

The scale should not be used as a straightedge nor should the compasses be set upon it to obtain desired distances. Any measurement wanted may be directly laid out by placing the scale upon the paper and pointing off the distance with a sharp pencil.

Thumb-tacks require no great care. When taken out in order to remove a drawing from the board, they should be lightly pushed into some out of the way place on the board so that they shall not be brushed onto the floor, and that the hands may not be accidentally placed on the upturned points.

Drawing pencils should be sharpened to have points about an inch long and should always be kept in good condition.

For drawing lines the wood should be trimmed with a knife to form a square point and the lead then brought to a flat or chisel edge, as it is called, by means of a file or sharpener. See Figure 40.

A round pointed pencil will also be found very convenient. The bother of keeping two pencils constantly at hand, the inconvenience of frequently laying down one to pick up the other, and the annoyance of usually getting the wrong one, may all be avoided by sharpening the two ends of one pencil. Of course, in so doing the grade mark will be cut from the pencil, but the proper number of circles or some similar mark cut in the wood, at the centre of the pencil when it is first sharpened, will always indicate the grade. In using the chisel-edge, the flat side should be laid against the straightedge and the pencil carried along from left to right with a light, but firm and even pressure. Hold the pencil in the manner advised for holding the pen, not that it is

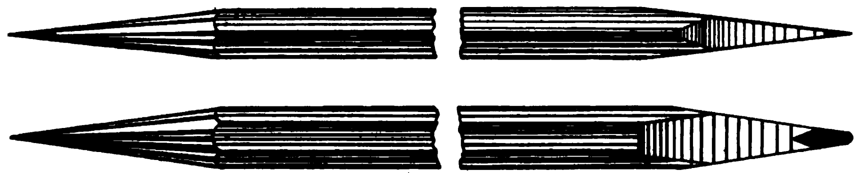


Figure 40.

absolutely necessary, but because it gives excellent drill for holding the pen, besides being desirable in itself. Do not let the pressure be heavy enough to indent the paper, as such marks cannot be completely erased. Use, rather, a softer pencil with light pressure.

The Pencil Pointer may be kept in a little case of stiff paper—easily made with a few minutes' labor—to keep pencil-lead dust off the drawing.

The Pencil Eraser should be sparingly used. It will be found necessary in removing superfluous lines, and in cleaning the drawing, but its constant use should be strongly discouraged. Constant study, care, and neatness will obviate much apparent necessity for it.

The Ink Eraser should be used still more sparingly than the pencil eraser since the drawing is supposed to be free of errors and unnecessary lines before inking is begun.

Hence the demand for an ink eraser usually indicates carelessness or lack of skill. The ink eraser is also marked "paper cleaner," but the statement is misleading because the eraser is not fit for such purpose. Use the pencil eraser for general cleaning.

Drawing Ink, if bought in the liquid form, is ready for use and will be found the preferable kind for ordinary work.

Should it be desired to use the stick ink, an ink-saucer in which to prepare it will be found necessary. A slate saucer will be found the best, being most convenient in form and made of a material which furnishes just the right surface for grinding the ink smoothly. Place a few drops of water in the saucer, insert the end of the stick and rub it about till the ink has become perfectly black.

When a track is for a moment left behind the stick as it is pushed about, the ink may be considered fit for use. If any doubt on the matter exists, the question may easily be settled by trial with the pen on a piece of paper other than the drawing. Ink may be kept in a well covered saucer for some time after being ground up. Should the water evaporate and the ink become too thick, add two or three drops of water and mix thoroughly, using a small piece of India rubber to stir the ink.

Freshly ground ink will be found to work better and to cling to the paper better than that which has been standing some time. After grinding, the stick should be well wiped to prevent crumbling. Common writing ink should never be put in the drawing pen as the acid in it attacks the steel and destroys the pen.

Drawing Paper may be fastened upon the board by thumb-tacks unless a very considerable time will be necessary for the work or the drawing will require tinting or much fine work, in which cases it is better to stretch the paper. Directions for tacking paper upon the board will be given later.

The process called **stretching** is used in fastening a large sheet of paper on the drawing board for

advanced work, and is described elsewhere in the book.

Tracing Cloth or Tracing Paper should be cut large enough to permit the tacks holding it down to clear the drawing beneath. Paper-weights may sometimes be used to hold the cloth in place but are generally in the way. Should the cloth appear to have a greasy surface which prevents the ink from flowing smoothly, the trouble may be remedied by rubbing some powdered magnesia over the drawing surface with a piece of chamois skin. Before making a tracing the drawing-pen should always be tried upon a scrap of tracing cloth. It will be found that ink runs differently and the pen acts differently on tracing cloth from what it does on drawing paper. If a line is overdrawn or a blot is made, a piece of blotting paper should be applied to the error at once.

Most of the ink will be absorbed by the blotter and the remainder may be removed by an ink eraser carefully used.

Water colors for use on tracing cloth should be mixed somewhat thicker than usual and should be applied to the back or dull side of the cloth.

Use of Section Paper and Water Colors.—As section paper, the section liner, water colors, and water color brushes are used only in advanced drawing, the descriptions of the methods of using them are not given here but will be found in the latter part of the work.

TIME SCHEDULES FOR DRAWING COURSE.

On the succeeding four pages appear some schedules showing the amount of time a pupil should put on each part of the work outlined in this book, in order to carry on the work to good advantage.

These schedules have been carefully compiled and averaged from the work of many pupils and afford excellent guides by which the progress of a pupil may be judged.

The schedules are arranged for a school year of forty weeks, the first schedule allowing for five mechanical drawing periods per week, and the second one for four periods for mechanical drawing and one for freehand drawing. While it is not supposed that all schools can use these schedules without modification, still some can, and in any case the schedules show the relative proportion of time that may properly be assigned to the various problems or other parts of the work.

The months as named in these schedules do not correspond exactly with the calendar months, but are what may be termed school months, and agree with the record and attendance books provided by the school management for the use of the teachers.

It is evident that these schedules as here given, cannot be correct for any two successive years, since some of the holidays named are movable, and most of them occur at slightly varying times in reference to the school year.

The general arrangement, however, and the amount of time assigned each part of the work are sufficiently accurate in many instances, and in any case afford the teacher excellent bases on which to found the calculation for any new arrangement of the work or assignment of time that may seem to him advisable according to the circumstances of the particular case under consideration.

TIME SCHEDULE OF PROBLEMS IN PART 1.

Arranged for 45 Minute Periods, 5 Periods per Week, and 40 Weeks per Year.

			MON	TUE	WED	THU	FRI
1	SEP.	1	Labor Day	Dismiss	Tools		
2		2	Lettering				
3		3			1–6		
4		4					
5	OCT.	1	7–12				
6		2			13–18		
7		3				19–24	
8		4				Exam.	
9	NOV.	1		25			
10		2					
11		3	26–27				
12		4		Exam.	28–29	Thanks'g	Holiday
13	DEC.	1					30
14		2					31
15		3					32
16		4		Exam.		Christmas	Holiday
17	JAN.	1		33			
18		2		34			
19		3			35		
20		4			36	Exam.	

TIME SCHEDULE OF PROBLEMS IN PART 1, CONTINUED.
Arranged for 45 Minute Periods, 5 Periods per Week, and 40 Weeks per Year.

			MON	TUE.	WED.	THU.	FRI.
21	FEB.	1					
22		2	37				
23		3		38			
24		4	Wash B'day		39	Exam.	
25	MAR.	1				40	
26		2					41
27		3					42
28		4				Exam.	43
29	APR.	1				44	
30		2		45			
31		3				46	Gd. Friday
32		4				Exam.	Closing
33	MAY.	1		47			
34		2					48
35		3				49	
36		4			50	Exam.	
37	JUN.	1	Dec. Day			51	
38		2		52			
39		3	53			Exam.	Exam.
40		4	CLOSING				

TIME SCHEDULE OF PROBLEMS IN PART 1.

Arranged for 60 Minute Periods, 4 Periods per Week, and 40 Weeks per Year.

			MON.	TUE.	WED.	THU.	FRI.
1	SEP.	1	Labor Day	Dismiss	Freehand	Tools	Tools
2		2	Lettering		"		
3		3		1 — 6	"		
4		4			"		7 — 12
5	OCT.	1			"		
6		2		13 — 18	"		
7		3			"		19 — 24
8		4			"	Exam.	
9	NOV.	1		25	"		
10		2			"		
11		3	26 — 27		"		
12		4		Exam.	"	Thanks'g.	Holiday
13	DEC.	1	28 — 29		"		
14		2	30		"		
15		3	31		"		
16		4	32	Exam	"	Christmas	Holiday
17	JAN.	1			"	33	
18		2			"	34	
19		3			"		35
20		4			"	Exam.	

TIME SCHEDULE OF PROBLEMS IN PART 1, CONTINUED.

Arranged for 60 Minute Periods, 4 Periods per Week, and 40 Weeks per Year.

			MON.	TUE.	WED.	THU.	FRI.
21	FEB.	1			Freehand	36	
22		2			"		
23		3	37		"		
24		4	Wash B'day.	38	"	Exam.	
25	MAR.	1			"	39	
26		2			"	40	
27		3			"		41
28		4			"	Exam.	
29	APR.	1	42		"		43
30		2			"	44	
31		3	45		"		Gd. Friday
32		4			"	Exam.	Closing
33	MAY.	1	46		"		
34		2	47		"		
35		3			"	48	
36		4		49	"	Exam.	
37	JUN.	1	Dec. Day	50	"		
38		2	51		"	52	
39		3	53		"	Exam.	Exam.
40		4	CLOSING				

CONVENTIONAL LETTERING OF DRAWINGS.

Mechanical drawings are always rendered in conventional style, of which one of the important features is clear and systematic lettering.

The draftsman should, as soon as possible, adopt some simple form of letters and practice carefully and constantly, till he can make the letters quite accurately and with sufficient rapidity. In Figure 41 are shown two forms of letters that may be easily and quickly acquired, and that are quite sufficiently elaborate for geometrical and machine drawing.

Freehand Lettering is shown in alphabets Nos. 1 and 2.

Mechanical Lettering is shown in alphabets Nos. 3, 4 and 5.

Geometric Lettering is a term also frequently applied to the forms shown in alphabets Nos. 3, 4 and 5.

Alphabets Nos. 1 and 2 present a form of letters suitable for geometrical drawings, also for notes, dimensions and detail titles on construction or working drawings. They are to be made with an Esterbrook's No. 621, or a Gillott's No. 404 or some similar pen and done at once in ink, that is, without being previously outlined in pencil.

The beginner should practice with the pencil until he has acquired the forms of the letters, but he should aim to execute with the pen alone as soon as possible.

Light pencil lines to determine the positions of letters and to give the letters correct and uniform heights should always be drawn. As an introductory exercise to his course of drawing the student should execute a sheet of lettering for which the following directions will be of assistance.

Place upon the drawing board, the ruled sheet of standard dimensions—10 in. x 13½ in.—prepared for the purpose and forming a part of the outfit. The paper should be fastened about four inches from the side nearest the draftsman and a similar distance from the left edge. The holes by which the paper is bound into the portfolio should be at the left hand. Put a thumb-tack through the upper or furthest hole. Place the T-square upon the board with the head firmly against the left edge of the board. Seize the paper by the lower right hand corner and swing it upon the thumb-tack already placed, as a pivot, till the upper edge of the paper is parallel with the upper edge of the T-square. Hold it in that position and fasten it in place by a

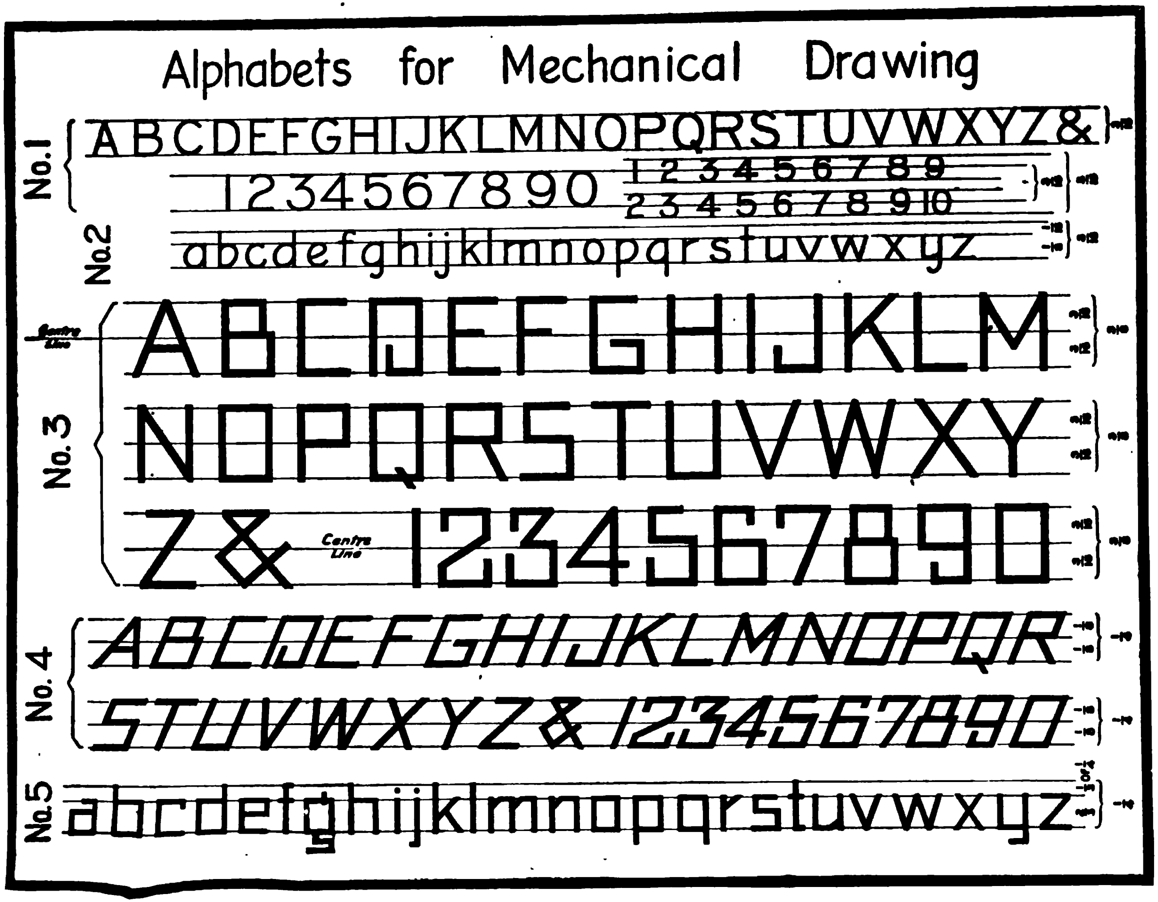


Figure 41.—Standard Alphabets.

second tack at the lower right hand corner, but placed just outside the paper. Place another tack at the upper right hand corner—also just outside the paper—and complete the fastening by putting a fourth tack through the second binding hole.

It is usual to require a draftsman to keep time on his work so that the cost of the drawings may be known when it is desired to fix the price of the object made from his drawings.

Time is to be kept on each of the drawings in this course in the following manner: Between the thumb-tacks put through the holes punched in the paper, draw two lines $\frac{1}{8}$ in. apart and parallel to the left edge of the paper. These lines are to be made in pencil only, and will be erased in the final cleaning of the drawing. Beginning at the thumb-tack nearest him, the pupil is to write his name between the lines just drawn, using them to determine the heights of the small letters, and making the capitals a trifle larger. Following his name, the pupil is to write the date on which the drawing is begun, stating the month, day and year.

Next, a space is to be allowed for the date of completion of the drawing in which similar items may be placed. Near the further thumb-tack the words—Time—and—Hrs.—(hours) with a small space between them are to be placed.

Next pencil a border to the sheet in the following manner. Place the scale across the paper vertically, or from front to rear, adjusting it so that it extends an equal amount over each edge of the paper, in which case the 6 in. mark will fall on the center line of the paper. Lay off each way from the center, distances of four and one-half inches, and there make small dots. Around these dots draw roughly and quickly—freehand—but quite lightly, very small circles, by means of which the points may readily be found. One-half inch from the right hand edge make a third point and twelve inches to the left of it place a fourth. Through the first and second points draw horizontal lines by means of the T-square. Through the third and fourth dots draw vertical lines, using T-square, and triangle. The result is a rectangle nine by twelve inches in size. Do not lay off these border lines by measurement from the several edges of the sheet. The result would be the same if the sheet were exactly correct in dimensions but frequently it is not, and the method is not right because it takes something for granted—in this case that the size of the sheet is correct—which is not an allowable thing to do in scientific work. The space enclosed by the border lines is the part to be used, therefore it is the part to be measured and made exact, and the error if any should be thrown into the border space which is the unimportant part.

Always throw any possible error of measurement into that part where it will work the least harm.

Inside the border lines and distant from them one-fourth inch, draw four other light pencil lines form-

ing a rectangle eight and one-half inches by eleven and one-half inches. All lettering is to be confined within the limits of the inner rectangle, thus keeping the work at least one-quarter inch from the border. The inner rectangle is to be erased in cleaning the sheet.

If the student is not supplied with this ready ruled sheet he may prepare one himself according to the following directions, taking care to execute it with the greatest accuracy else it will be of no value. It is strongly recommended that the pupil be furnished with a ready ruled sheet because a beginner finds much difficulty in doing this ruling sufficiently well.

If the student is supplied with the ready ruled sheet he need pay no attention to the following directions on laying out lettering lines, but should pass on to the succeeding paragraphs.

Beginning with the upper line of the inner rectangle lay off distances as follows: 1/16 in., 1/8 in., 1/16 in., 1/8 in., 1/8 in., etc., to the lower border line of the inner rectangle. In laying off these distances, place the scale across the paper vertically and mark off the spaces with a finely pointed pencil. Do not move the scale in the process, as frequent resetting of the scale is liable to lead to error. Through the points thus made, draw very light horizontal pencil lines clear across from side to side of the inner rectangle. These lines are to determine the heights of the letters; 3/16 in. for the capitals and tall letters; 1/8 in. for the smallest letters.

Next, with the T-square and triangle draw entirely across the horizontal lines just made, a set of vertical lines. These latter lines are only to aid in determining the direction of the letters. They should be made about ⅜ in. apart, but this distance need not be exact and may be determined by the eye. The lines last described complete the ruling necessary for the practice sheet. They are not to be drawn after the pupil has attained proficiency in lettering.

A few lines of letters may now be made in pencil. The pupil should stand with his left side against or towards the front edge of his board, with his left arm thrown well forward on the drawing board, thus bringing his right forearm as he letters, at right angles to the horizontal lines on the paper. The pencil should be held easily and the hand be supported on the third and fourth fingers, the palm being turned well down. In this position the pen or pencil will point over the right shoulder. Observe this position closely. Good lettering cannot be done with the hand resting on its side and the pen pointing away from the body. The position here recommended allows the pen to be easily drawn downwards in the proper direction and gives free action to the nibs. Do not attempt to determine the width or spacing of the letters by the penciled direction lines as they are intended merely for guides to give

the proper direction to the main lines of the letters. Keep these main lines, especially of such letters as b, d, g, h, l, p, etc., quite straight. See that the bodies of the letters are well rounded. Study the copy closely for every letter and each individual line in the letter. Do not fall into the error of using a line of letters just executed as a copy for the succeeding line. Follow carefully in the order given these itemized directions for filling the sheet of standard freehand lettering.

1st. Place name of pupil, date of beginning work on this sheet, and the abbreviations, "Time" and "hrs."

2nd. Make the border for the sheet.

3rd. Lay off the lettering lines if a ready-ruled sheet is not in the outfit.

4th. Draw direction lines for the letters, using the 2-H pencil, triangle and T-square. Make the lines very light, about 3/8 in. apart, and space them by the eye only.

5th. Space the letters as shown in the plate of standard alphabets, Figure 41, alphabets Nos. 1 and 2.

6th. Fill the sets of lines Nos. 1, 2 and 3 inclusive, of the lettering sheet with capital letters only, like those shown in alphabet No. 1. Make them freehand, in pencil only and very lightly. Use the 2-H pencil for this work.

7th. Fill the sets of lines Nos. 4, 5 and 6 inclusive, of the lettering sheet with small letters only, like those shown in alphabet No. 2. Make them freehand, in pencil only and very lightly.

8th. Fill set of lines No. 7 with numerals only, like those shown in alphabet No. 1. Make them all integers. Make them freehand, with pencil only, and very lightly.

9th. Fill set of lines No. 8 with numerals only, in pencil. Make them all fractions as shown in alphabet No. 1. Make each figure in every fraction two-thirds the size of an integral figure—that is, 1/8 in. tall. Do not make a division line between the numerator and the denominator. Allow 1/16 in. blank space between the numerator and the denominator. When the fraction is correctly made and placed, the center of the numerator lies upon the upper lettering line and the center of the denominator lies upon the lower lettering line.

10th. Fill set of lines No. 9 with capitals only, in pencil, made freehand style as before.

11th. Fill set of lines No. 10 with numerals only, in pencil. Make them all mixed numbers. Observe carefully the shapes, proportions and placings of the integers and fractions comprising the mixed numbers.

12th. Fill sets of lines Nos. 11 and 12, with capitals only, in pencil, made freehand style.

13th. Fill sets of lines Nos. 13 and 14, with small letters only, in pencil, made freehand style

14th. Fill set of lines No. 15 with numerals only, in pencil. Make them all integers and in the same freehand style.

15th. Fill set of lines No. 16 with numerals only, in pencil. Make them all fractions, in the same freehand style.

16th. Fill set of lines No. 17 with small letters only, in pencil, made freehand style.

17th. Fill set of lines No. 18 with numerals only, in pencil. Make them all mixed numbers in the same freehand style.

18th. Ink sets of lines Nos. 11 to 18 inclusive, using Esterbrook's No. 621, or Gillott's No. 404 writing pen, and black drawing ink.

19th. Fill set of lines No. 19 with capitals, made freehand, in ink only, using the same writing pen.

20th. Fill set of lines No. 20 with small letters, made freehand, in ink only.

21st. Fill set of lines No. 21 with numerals, all integers, made freehand, in ink only.

22nd. Fill set of lines No. 22 with numerals, all mixed numbers, in ink only.

In the last five sets of lines the letters should be grouped into words and paragraphs for which these instructions will furnish a convenient and appropriate text beginning with this paragraph. Be sure to keep the letters of each word close together and the words well separated. Allow a space of at least ¼ in. between any two words.

This space of *¼ in. is,* of course, proper only for this alphabet or one of similar proportions. In any style of alphabet it will answer very well to allow a space equal to the width of one and one-half letters between any two words. In this way the words will stand out boldly and clearly.

The sheet should be filled with lettering unless the pupil becomes sufficiently skillful before he has done so much.

23d. Fill sets of lines Nos. 23 and 24 with words, made freehand, in pencil only. Allow ¼ in. blank space between the words.

24th. Fill set of lines No. 25 with words, in pencil, and then finish them in ink.

25th. Fill sets of lines Nos. 26 and 27 with words, in ink only.

After the sheet has been filled it will, if satisfactory, be accepted by the inspector who will signify his approval by affixing his signature.

The pupil will then ink the 9 in. by 12 in. border, making the lines of the proper width for borders, see plate of standard lines, Figure 53, page 79. He will next ink the draftsman's name, date of beginning work on the sheet, date of finishing same, and the time spent thereon. These items are to be written, thus fully identifying the maker of the drawing. The sheet is then to be cleaned, and presented to the inspector for his second and final signature which having been affixed, the sheet is to be removed from the board and filed away in the portfolio.

The remaining alphabets, Nos. 3, 4 and 5, Figure

41, are intended for the titles of large sized working drawings and are to be made with instruments.

Alphabet No. 4 is a modification of alphabet No. 3. The slant of the letter is $67\frac{1}{2}°$, and a lettering triangle having one of its sides inclined at the angle named will be found a great convenience.

Alphabet No. 5 shows the shapes of the small letters to accompany alphabet No. 3. In size, however, they correspond with alphabet No. 4.

It is to be understood that the proportions of the letters in any alphabet may be changed at the option of the draftsman to accommodate the purpose for which they are used and the position in which they are placed.

In this course, however, all lettering is to be executed in the standard proportions shown whenever possible, and any variations must be through necessity and done only with the approval of the teacher. The rule usually adopted for lettering is to make the small letters two-thirds the height of the capitals, except such letters as b, h, p, etc., which are of equal height with the capitals. Small letters to accompany alphabet No. 4 may be made by inclining the letters shown in alphabet No. 5. These last three alphabets are to be lightly and quickly but roughly sketched in pencil, accuracy of line and form being attained by use of the ruling pen, T-square and triangles. Further particulars as to drawing these alphabets are given under Machine Drawing.

In Figure 53 is shown an alphabet designed for architectural work.

DIRECTIONS FOR MONTHLY PRACTICE LETTERING.

The following text is to be used by the pupils as the subject matter for monthly lettering sheets, commencing with the following word:—

Directions for monthly practice lettering sheets.

I have carefully read all of these directions.

One 5 in. by 6¾ in. practice sheet of lettering is to be executed monthly by each pupil and handed in on or before the beginning of the recitation hour on the last Thursday of each school month, which Thursday is the regular monthly examination day. Notice that the school month does not always correspond with ◊ the calendar month.

If for any reason the monthly examination is held earlier than the last Thursday of the school month, the lettering sheet must be in by or before that earlier day. It is advised that the pupil shall not postpone this work till the last moment, but shall execute it as early in the month as may be convenient to him. Whenever and as soon as the sheet ◊ has been completed it should immediately be placed in the box or drawer provided for the purpose in the drawing room.

This work must be done entirely out of school and be handed in at the appointed time, otherwise it will not be accepted.

Divide the text here given and use it for the subject matter of the monthly lettering sheet as follows: September, first 70 words; October, second 70 ◊ words; December, third 70 words, etc. Use just seventy words counting each group of figures as one word, even if by so doing the assignment stops in the middle of a sentence.

Begin each month's lettering where the assignment for the previous month stopped. Should any of these assigned portions not be sufficient to fill the sheet as required, insert numerals enough to fill the remaining space.

Vertical direction lines ◊ for the lettering must be drawn across the sheet in pencil and allowed to remain. Space the direction lines about ⅜ in. apart. Begin the lettering at the left extremities of the horizontal lines and fill each set of lines except the last, with words or numerals.

The lettering must be executed in black drawing ink with an Esterbrook's No. 621, or a Gillott's No. 404 writing pen.

The style ◊ of letters and figures to be used is that shown by the plate of standard lettering in alphabets No. 1 and No. 2.

Follow carefully all directions for executing free-

hand letters and numerals that have been previously given. Do not hand in any sheets which lack evidence of faithful work and conscientious endeavor.

Notice that in the list of assignments for the different months, no mention is made of one ◊ for November. The sheets handed in for November, February and May—every third month—are to be filled with numerals instead of lettering.

Each sheet of numerals is to be filled as follows: Number the sets of lines. Then fill the first five sets of lines with numerals, making them all integers, 0 to 9 inclusive, repeated. Sixth and tenth sets of lines, all common fractions. Seventh, ninth, and eleventh ◊ sets of lines, all integers. Eighth and twelfth sets of lines, all mixed numbers.

Each sheet of lettering or numerals must bear in writing on the last set of lines, first, the surname of the pupil; and in printing, second, the number of his drawing period in the day—expressed as 1st Pd., 2d Pd., 3d Pd., etc., as the case may be; third, the date of executing the work; ◊ and fourth, the time expended upon it.

These four items must be put on in the order here given. The month must be named, its number will not suffice.

Failure to comply with the foregoing requirements will cause the sheet to be rejected. Each perfect sheet will be accepted as ten per cent of the entire month's work in mechanical drawing.

The best and the poorest specimens of work ◊ from each class will be put up in the drawing room each month for comparison and criticism.

In each class the pupil presenting the poorest lettering sheet for any month will be required to hand in two sheets on the following month instead of one. In each class the pupil presenting the best sheet for any month will be excused from making a similar sheet for the following month (only), ◊ and given full credit for work satisfactorily performed for each of the two months, provided he makes a request to that effect of his teacher before examination day, and sees that the teacher makes in his presence the necessary record of excuse with credit.

THE ESSENTIALS OF A GOOD MECHANICAL DRAWING.

The essential features of a good mechanical drawing are as follows:—

1st. **Accuracy.** Under no circumstances should a drawing misrepresent the ideas meant to be conveyed, as that would render it worse than useless.

2nd. **Definiteness.** There must be no doubt as to the meaning intended, and no possibility of different interpretations by different people.

3rd. **Completeness.** The information conveyed should be so exact and entire as to leave nothing further to be desired.

4th. **Simplicity.** Let the drawing be as little complicated as possible. A multiplicity of unnecessary lines confuses the workman and wastes both his time and the draftsman's, besides possibly leading to error.

5th. **Uniformity.** When any certain style of finishing drawings has been adopted as being satisfactory, all drawings in the same set, or made in the same drafting room should conform to that style. This tends to avoid confusing any workman who has occasion to use the drawing either in the drafting room or the work shop.

6th. **Neatness.** This point needs no explanation but should receive great attention. In order to protect drawings from dust they should, while being made, be covered by a paper or cloth, preferably the latter, at all times when work is not being done on them.

Whenever a drawing is taken from the drawing room, it should be carried in the portfolio so that it shall not be crushed, wrinkled, or otherwise damaged.

PENCILING AN ELEMENTARY DRAWING.

All the pencil work of a drawing should, as a rule, be completed before any inking is done. Experience will best teach the beginner when this rule may be broken—which is very seldom. Penciling is the constructive process of drawing, and as the prime object of mechanical drawing is to make accurate construction possible, great stress is laid upon exactness in this part of the work. Neatness and accuracy should always be aimed at, and success in attaining them depends in great measure on the nicety with which the penciling is done. Observe closely the following directions:

1st. **Pencil lightly.** Let the marks of the pencil be as fine and light as possible and yet have them easily visible. Keep the drawing pencil and the leads in the compasses sharp and in the very best condition as regards shape.

2nd. **Pencil clearly.** Erase immediately all overdrawn lines and any that are not positively required in the representation of the object.

3rd. **Pencil the drawing as it is intended that it shall be inked.** As much as possible omit all lines that are not needed in the finished drawing. The neater and more skillful a draftsman is, the less need he will give himself to use a pencil eraser. Make all lines dotted or full according as they should finally be. This tends to avoid confusion, allows the drawing to be more easily read, and lessens the possibilities of error when inking the drawing.

4th. **Work rapidly.** Employ the best methods in laying out work and plan ahead as far as can well be done. Learn to use the instruments skillfully and perform as much work as possible with any one of them before changing to another. As nearly as may be, execute all work of any one class at the same time.

After the drawing has been neatly finished in pencil to fully correspond with these directions as nearly as the pupil can judge, it is to be submitted to the inspector who will offer such suggestions and corrections as may seem necessary. The pupil will then revise and correct his work and again submit it. When it has been made acceptable to the teacher the latter will affix his signature which is to be understood by the pupil as permission and direction to finish his drawing in ink.

PLANE GEOMETRY.

FUNDAMENTAL DEFINITIONS AND PROPOSITIONS.

Geometry is the science which treats of position, form, and magnitude. Points, lines, surfaces and solids, with their relations to each other, constitute the subject matter of geometry.

Mechanical drawing is based upon a study of the science of geometry, employs many of its terms, figures and methods, and is therefore properly introduced by a consideration of them.

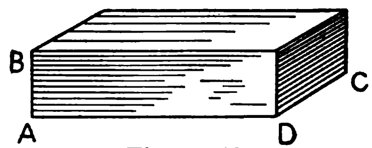


Figure 42.

In Figure 42 is represented an ordinary brick, which is called a solid because it is correctly described as follows:—

A solid is a body which has a fixed form and occupies a certain amount of space.

The outside of a solid is its **surface.** Any one of the parts which compose the surface of a solid is a **face.**

The edge in which any two faces of a solid meet is called a **line.**

The place in which any two lines meet is called a **point.**

By reference to Figure 42 it will be seen that the solid shown there has faces of three different shapes. To compute the volume of the brick it would be measured in three principal directions:

1st. The greater horizontal dimension, A to D, which is called the **length.**

2nd. The smaller horizontal dimension, D to C, which is called the **width** or **breadth.**

3rd. The vertical dimension, A to B, which is called the **thickness, height** or **depth.**

The measurements of an object showing its size are called **dimensions.**

A solid has three dimensions, length, width and thickness.

A surface is considered as the boundary or limit of a solid.

A surface has only two dimensions, length and width.

A line is considered as the boundary or limit of a surface.

A line has only one dimension, length.

A point is considered as the extremity or limit of a line. The place where two lines intersect is also a point. A point has position but no dimension.

In practical work a point is represented by a fine dot and named by a letter, as E, Figure 43.

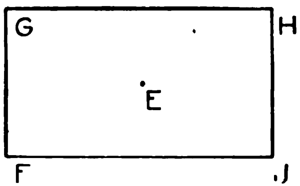


Figure 43.

A line is named by two letters placed one at each end, as F J, Figure 43.

A surface is represented and named by the lines bounding it, as F G H J, Figure 43.

Lines may be either straight, broken or curved.

A straight line is one which has the same direction throughout its length, as K L, Figure 44.

A straight line is also called a **right line.**

A straight line is usually called a line simply, and when the word line occurs in the following text, it is to be understood as meaning straight line unless otherwise specified. A straight line is the shortest distance between two points. If any other path between the points were chosen, the line would become curved or broken. Therefore two points determine the position of the straight line joining them.

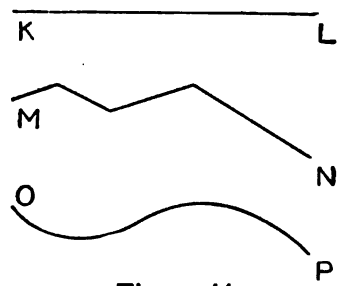


Figure 44.

A broken line is one which changes direction at one or more points, as M N, Figure 44.

A curved line is one which changes direction constantly throughout its length, as O P, Figure 44. The word curve is used to denote a curved line.

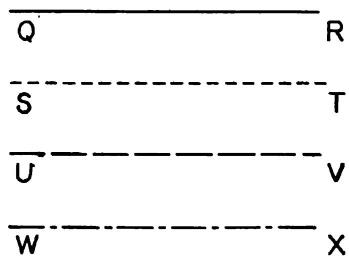


Figure 45.

Lines may be represented as full, dotted, dashed, or dot-and-dashed.

A full line is one which is continuous throughout its length. See line Q R in Figure 45.

A dotted line is one which is composed of alternate dots and spaces. See line S T in Figure 45.

A dash line (usually so-called) is one which is composed of alternate dashes and spaces. See line U V in Figure 45.

A dot-and-dash line (usually so-called) is one which is composed of dots, spaces, and dashes. These may be arranged in several ways according to the character of the line, that is, the meaning it is to convey. One kind of dot-and-dash line is shown by W X in Figure 45.

Surfaces may be either plane or curved. A plane surface is usually called a plane.

A plane is such a surface that if a straight line be applied to it in any direction, the line and the surface will touch each other throughout their length. Thus the surface of a drawing board is a plane if the edge of a T-square (provided such edge be perfectly straight) when applied to the board, touches at every point of its length.

A curved surface is one no part of which is a plane.

Any combination of points, lines, surfaces or solids is termed a **figure.**

A plane figure is one which has all of its points in the same plane.

Plane geometry treats of figures whose points all lie in the same plane.

Lines may be so situated as to be parallel or inclined to each other.

Parallel lines are those which have the same or opposite directions. Parallel lines are everywhere equally distant. Parallel lines will not meet however far produced.

Inclined lines are those other than parallel. Inclined lines will always meet if produced far enough. Their mutual inclination forms an angle.

An angle is the difference in direction of two lines. Figure 46 shows an angle.

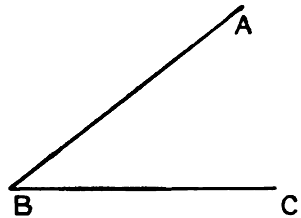


Figure 46.

An angle is also defined as the opening between two straight lines which meet or would meet if produced.

The two lines which form an angle are called the **sides of an angle.**

The point in which the sides of an angle meet is called the **vertex** of the angle.

An angle is named by three letters, two of which are placed at the extremities of the sides and the third is placed at the vertex. Figure 46 shows the

angle A B C. In reading an angle the letter designating the vertex is used as the middle letter.

The size of an angle is the amount of opening between its sides. The size of an angle does not depend upon the length of its sides.

Equal angles are those which have the same amount of opening between the sides.

Two angles are called **adjacent angles** when they have the same vertex and a common side between them. Figure 47 shows the adjacent angles D E G and G E F.

A right angle is formed when one straight line meets another straight line so as to make the adjacent angles equal. The angles shown in Figure 47 are right angles.

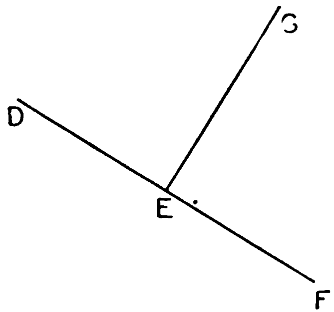


Figure 47.

A perpendicular is a straight line that meets another straight line so as to form a right angle. Thus in Figure 47, G E is a perpendicular to D F. Also D F is a perpendicular to G E. It will be evident by considering Figure 47 that two right angles and only two can be formed at the same point and on the same side of a line.

The foot of a perpendicular is the point in which it meets the line to which it is perpendicular. In Figure 47, E is the foot of the perpendicular G E.

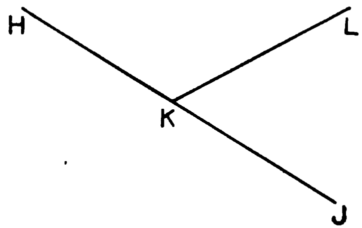


Figure 48.

An acute angle is one less than a right angle. In Figure 48, L K J is an acute angle.

An obtuse angle is one greater than a single right angle and less than the sum of two right angles. In Figure 48, H K L is an obtuse angle.

An oblique angle is one other than a right angle. It may be greater or less than a right angle. In Figure 48, H K L is an oblique angle, also L K J is an oblique angle.

An angle may be generated by revolving a line about one of its extremities which remains fixed.

Thus in Figure 49, several angles N M O, O M P,

P M Q, etc., are generated by the revolution of the line M N about its extremity M.

If a complete revolution is made the moving extremity describes a circumference.

A circumference is the curved line which bounds a circle. The line N O P Q R S, in Figure 49, is a circumference.

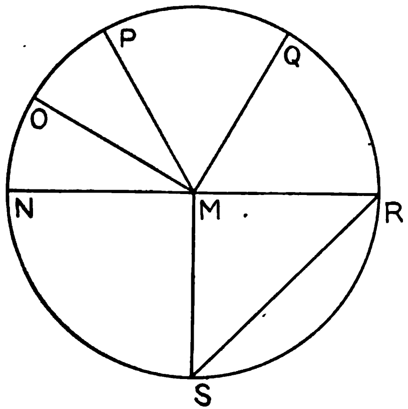


Figure 49.

A circle is a portion of a plane bounded by a curved line, all points of which are equally distant from a point within called the **center.** The plane figure N P R S, Figure 49, is a circle.

Any portion of a circumference is called an **arc**; as P Q, Figure 49.

A radius is any line drawn from the center to the circumference of a circle. M N, Figure 49, is a radius.

A chord is a straight line having its extremities in the circumference. A chord is the straight line joining the extremities of an arc. The straight line R S, Figure 49, is a chord.

A diameter is a chord passing through the center. It is equal to twice the radius. N R in Figure 49 is a diameter.

To designate different portions of the line generating a circle, and to measure the size of the resulting angle and the corresponding arc, the circumference is supposed to be divided into 360 equal parts called **degrees.**

An angle is measured by the length of the arc included between its sides and struck from its vertex as a center.

PREPARING THE PAPER FOR PROBLEMS IN PLANE GEOMETRY.

Fasten a sheet of paper on the board and place the draftsman's name and other required data. Present the drawing to the drawing inspector so that he may affix his signature with date and make any memoranda that he may desire in order to keep himself fully informed concerning the progress which the draftsman is making. This is to be done regularly during the remainder of the course. The draftsman must also keep his own record as has

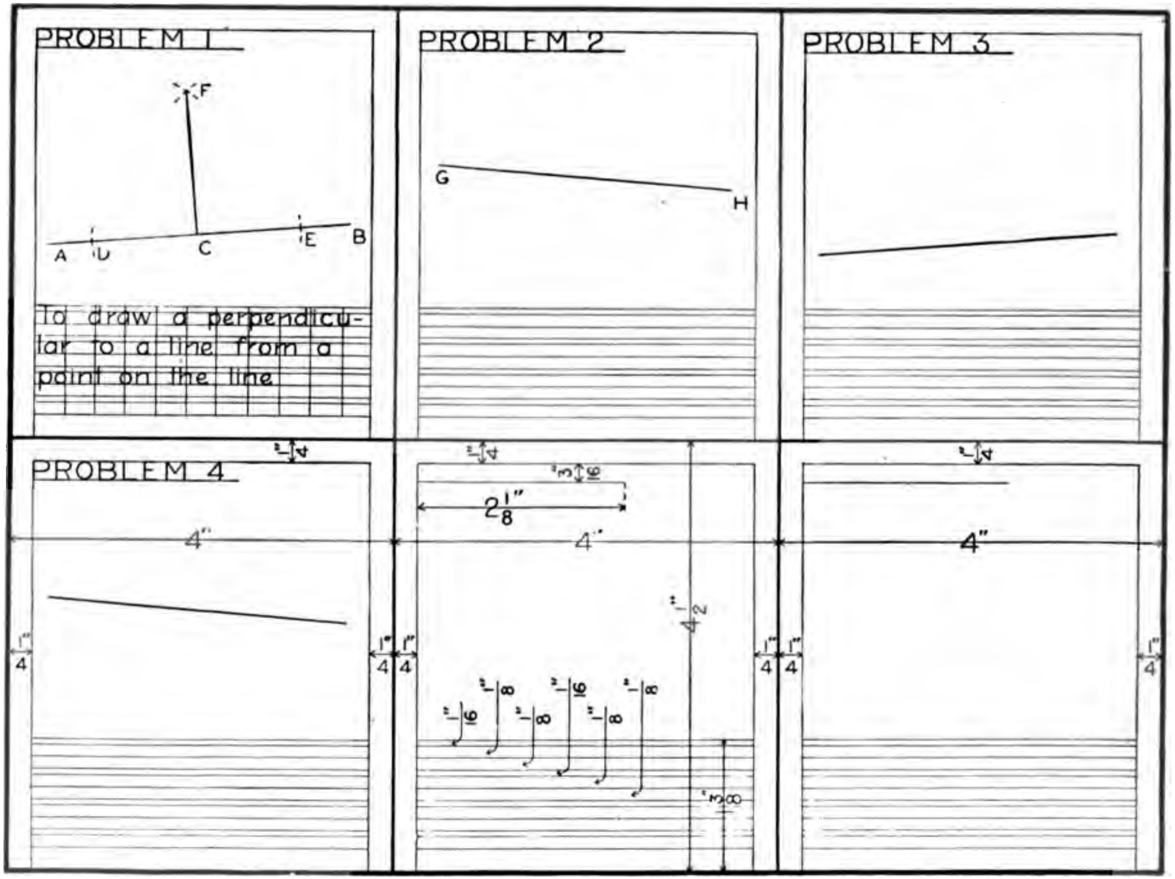


Figure 50.—Layout of Paper for Problems 1 to 6 inclusive.

been previously explained. Pencil a 9 in. x 12 in. border as explained on page 56 and following pages. Divide the space enclosed by the border into equal parts by one horizontal and two vertical lines, forming six rectangles each 4 in. by 4½ in. See Figure 50. Inside each rectangle and ¼ in. from its sides, draw three lines, one at the top and one at each side.

Between these inside lines and 1⅜ in. from the bottom line of the rectangle draw a horizontal line forming the upper line of four sets of lines laid off at the regulation distances for lettering as shown in Figure 41, and upon which the title is to be placed. Do not move the scale when spacing these lettering lines. Do not reset the T-square for the lettering lines of each rectangle, but having set it for any line in either of the left hand rectangles draw at the same time corresponding lines in the rectangles horizontally opposite.

Complete the ruling for the lettering of the sheet as shown in the diagram, Figure 50, by lines placed 3/16 in. below the upper inner border line of each rectangle and extending from the left inner border half way across the rectangle. Make all the lines very light so that the finished work may not be spoiled in the final cleaning of the drawing. Do not copy the lines and figures showing distances and dimensions. They are placed on the diagram only to show how it is laid out. Make the ruling as accurate as possible. Good lettering cannot be done when the lines are unevenly and incorrectly placed.

GENERAL DIRECTIONS FOR PENCILING GEOMETRICAL DRAWINGS.

After the ruling for a sheet of geometrical problems has been completed, proceed with the constructions of the problems. Finish the drawing of each problem in pencil before putting in its title.

All geometrical problems are to be constructed with pencil, straightedge and compasses only. Put all other tools away.

Given lines are not to be drawn with the T-square in combination with the drawing board, but should be made with a triangle used as a straightedge.

Incline the given line of each problem slightly—about ¼ in. from horizontal in the length of the line—and successively in opposite directions—for the purpose of giving balance to the drawing. See ruled diagram, Figure 50, in which Problem 1 is already drawn, and the position shown for the given line in the next problem.

Given and required lines are to be full lines. All construction work is to be made in dotted lines.

Draw intersecting arcs a very short distance—

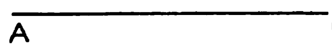


Figure 51.

about ¼ in. only, as nearly as can be judged—each side of the point of intersection.

Letter all points of construction as soon as used,

and in consecutive order thus: given line, A B, see Figure 51; given point, C; first point used in construction, D; next point used in construction, E; etc.

Lettering the points of construction in this manner is imperative as it shows quickly and clearly the method used for solving the problem.

Omit the letter I because it looks so much like the numeral 1.

Make each letter on the figures, a capital, ⅛ in. tall, and standing always in a vertical position regardless of how the figure is inclined.

Place each letter 1/16 in. to the right of and an equal distance below the point which it designates and always so as not to interfere with the border or any line of the drawing.

When the alphabet has beeen exhausted begin to repeat it.

When the figure has been completed place the heading—PROBLEM 1, or whatever number is proper—above the figure, beginning it in the upper left corner formed by the inner or clearance borders, and making the letters all capitals.

Next place the statement of the problem below the figure for a **title,** beginning it also against the left inner border. Make this title in capitals and small letters as any text is ordinarily printed.

Direction lines may be drawn for the lettering on this and a few following sheets of drawing if found necessary, but as soon as possible the pupil should learn to do without their aid.

Each sheet of geometrical problems is to be completed in pencil before any part of it is inked.

After the drawing has been carefully completed in pencil it is to be submitted to the inspector for examination and criticism. When approved by him it will receive his second signature which means that the drawing is accepted and is to be inked.

CONSTRUCTIONS OF GEOMETRICAL PROBLEMS.

PROBLEMS 1 TO 6 INCLUSIVE.

PROBLEM 1.

To draw a perpendicular to a line from a point on the line.

Construction:—Assume any line as the given line, inclining it from horizontal about 1/4 in. in its length. In this particular case in order that the drawing may be well laid out, the line is to be placed in the upper left hand rectangle, and near the lettering lines, as the construction work will be entirely on one side of the line. Letter the left extremity, or point of the given line A, and the right end or point B. See diagram Figure 50.

All lettering is to be in style of alphabets Nos. 1 and 2. Each letter is to be 1/8 in. tall, made vertical and placed 1/16 in. below and an equal distance to the right of the point it designates.

Next assume any point in the line—preferably one a short distance away from the center of the line—as the given point, and letter it C.

Set the needle point leg of the compasses at C. Open the compasses to such an extent that a curved line may be drawn which shall cut the given line at two points—one on either side of the given point. As these points where the given line is intersected are the only points in the curve which it is desired to use, most of the curve between these points may be omitted, leaving only two small portions of the curve. The curves cutting the given line are arcs. Make these arcs dotted lines because they are construction lines. Letter the left point of intersection D and the right one, E.

It is well to assume such a radius as shall bring the points D and E nearer to the extremities of the line A B than to the point C. From D and E as centers and with any radius greater than D C, draw arcs intersecting above the line. Letter the point of intersection F. Let the radius D F be as long as may be without encroaching on the space reserved for the heading PROBLEM 1.

Connect F and C and the line F C is the perpendicular required. F C should be a full line because it is a required line. Finish the drawing by placing the heading PROBLEM 1 above the figure, beginning it against the inner or clearance border 1/4 in. each

way from the upper left corner of the main border. Below the figure place the title of the problem—To draw a perpendicular—etc., beginning this also against the inner left clearance border.

After the problem has been carefully executed to the best of the pupil's ability, he is to review the directions, and also the general directions for geometrical problems on the pages immediately preceding, to see that his drawing complies with the requirements. If so, he is to read the draftsman's method for doing the same work. Professional draftsmen frequently have some quick method or special way of using instruments in doing work and some of these processes are here explained.

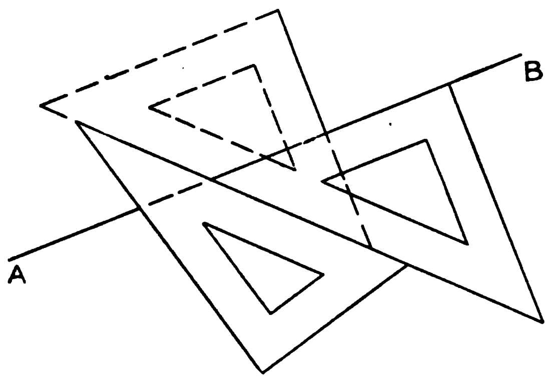


Figure 52.

Draftsman's Method:—If the given line is vertical, a perpendicular may be drawn with the T-square; if horizontal, with the T-square and a triangle; if inclined, then with two triangles as here explained.

Place the triangles together with their longest sides in contact, and adjust them so that a shorter edge of one shall coincide with the line to which it is desired to draw a perpendicular, as shown in Figure 52.

Then holding the other triangle stationary, slide the former back and forth along the stationary triangle till the edge of the moving triangle which is perpendicular to the edge that was originally adjusted to the line, is in position to draw the perpendicular as desired. The T-square may be used as a straightedge along which to slide the triangle but is rather more awkward to handle than a second triangle.

PROBLEM 2.

To draw a perpendicular to a line from a point outside the line.

Construction:—Assume the given line and mark it G H. Also assume the given point and mark it J. Place the given line about in the center of the space available for the problem as the construction work will fall on both sides of the line. Assume the position of the given point above the line and a little to one side of the center of the line taking care that the position so assumed does not interfere with the heading "PROBLEM 2." Set the compasses at J

as a center, and with any radius that will cut the line in two places near its extremities draw arcs intersecting the line G H at two points which mark K and L respectively. From K and L as centers and with any radius greater than one-half of the distance between K and L draw arcs intersecting below the line G H and mark the point of intersection M. Connect J and M and the line J M is the perpendicular required.

Complete the penciling of Problem 2 by placing the heading and title in a manner corresponding to that employed in the previous problem.

Draftsman's method:—Use the same method as that employed for Problem 1.

PROBLEM 3.

To draw a perpendicular to a line from a point at the end of the line.

Construction:—Assume N O for the given line and O for the given point at the end of the line. Place N O near the lettering lines. Assume any point P outside the line N O. Theoretically P may be placed any where, but for the sake of uniformity and the good appearance of the drawing, place it about ⅞ in. above the line and about an equal distance toward the left from O, the right hand end. Do not measure these distances but rely entirely upon the eye in placing the point. From P as a center and with the distance P O as a radius describe an arc passing through the point O and intersecting the line N O at a point which should be marked Q. Continue the arc from Q a sufficient distance to make it greater than a semi-circle. Connect the points Q and P, and prolong the line until it intersects the arc just drawn. Letter the point of intersection R. Connect R and O, and the line R O is the perpendicular required.

Draftsman's method:—Use the same method as that employed for Problem 1.

PROBLEM 4.

To bisect a line.

To bisect a figure is to divide it into two equal parts.

Construction:—Assume a line placed about midway of the space and mark it S T. From S and T as centers and with any radius greater than one-half S T, draw arcs intersecting above and below the line. Letter the upper point U, and the lower, V. Connect the points U and V by a line and place the letter W at the point where U V intersects S T. U V should be a dotted or broken line because it is a construction line and what is required in this case is the central or bisecting point merely. The given line S T is intersected by the line U V at the point W. The line U V is called a **bisector.** The points U and V are equidistant from the points S and T by construction, since they were made by using the same radius from each point. If a radius of

greater or less length had been used, the intersections would have fallen in the same line U V, and nearer to or farther from the line S T according to the radius used. It is evident, that each point of the bisector is equally distant from the points S and T. When the radii are of such length that the arcs just touch, they will meet at the point W which must be then midway between S and T. Observe that the bisector is perpendicular to the line at the middle point of the latter.

Draftsman's method:—The geometrical method may be used. Ordinarily the line is bisected by measurement with the scale. Dividers may be employed and the center point found by trial.

PROBLEM 5.

To bisect an arc.

Construction:—Assume an arc about midway of the space and mark it X Y. Let the radius of the arc be long enough so that the arc shall be rather flat, and approximate a straight line. Use 2½ in. as the length of the radius, placing the center from which the arc is struck near the upper right corner of the space in which the problem is drawn. Mark the position of the center by a dot for future reference and use.

If the points X and Y were joined by a straight line—the chord of the arc—this problem would be seen to be merely a repetition of the one just preceding. Imagine the line to be so drawn, and proceed to execute the problem according to the method used for the bisection of a straight line. The bisector will intersect the arc at a point B. This point must be the middle point of the arc because, since it is on the bisector, it is equidistant from the extremities X and Y. Extend the bisector and observe whether it passes through the center from which the arc was struck. It should do so if the problem has been well executed. Observe that the bisector of the arc, bisects the chord of the arc, is perpendicular to the chord at its center point and passes through the center of the circle of which the arc is a part.

Draftsman's method:—There is no special draftsman's method for this problem. Use the geometrical method.

PROBLEM 6.

To construct at a given point in a given line, an angle equal to a given angle.

Construction:—Assume a given line near the lettering lines, and select some point of the line as the given point. Any point of the line may be chosen, but for this problem let the point be near the left extremity of the line. Letter the line and the point. In the upper right hand part of the rectangle draw an angle for the given angle. This angle may be of any form and placed in any position, but assume it to be an acute angle with the

vertex towards the left. Do not make the angle by drawing around the corner of a triangle. Letter the given angle.

The size of an angle is measured by the length of an arc included between its sides and struck from the vertex as a center. Therefore comparison of the sizes of angles is made by comparing the arcs of the angles, but these arcs must be taken as parts of the same circumference, that is, they must be drawn with radii of equal length.

Find the size of the given angle and lay it off from the given line, at the given point in the following manner, taking great care to letter each point of construction as fast as made or used.

From the vertex of the given angle and with any radius, strike an arc crossing the sides of the angle, preferably at points nearer to the ends of the sides than to the vertex. With the compasses set at the same radius, strike an arc from the given point as a center so that it intersects the line and extends indefinitely on one side of it. Use the upper side, as the given line is near the lettering lines. Set the compasses to the length of the arc included between the sides of the given angle, and with this distance as a radius, and the point where the indefinite arc just drawn intersects the given line, as a center, strike a short arc across the indefinite arc. Through this intersection draw a line to the given point, and the angle thus formed with the given line is the required angle and is equal to the given angle.

Draftsman's method:—Use the geometrical method. A protractor may be employed.

GENERAL DIRECTIONS FOR INKING GEOMETRICAL DRAWINGS.

Inking is the last step in the construction of a finished drawing, and while not absolutely necessary, makes the drawing clearer, tends to preserve it, and gives to it a finish which in most cases justifies the extra labor expended.

Sheets of geometrical problems are to be inked wholly in black, and in the following order: problems, lettering, border, and lastly, the division lines that separate the space enclosed by the border into six equal rectangles.

Before commencing to ink the drawing try the pen on a piece of paper of the same kind as that on which the drawing is made, to see that the pen works well and gives the desired width of line. In thus trying the pen use the T-square or triangle so that the conditions shall be the same as for the drawing and that like results may be obtained in the two cases. Keep this paper at hand for trying the pen at any time. It is well to tack it upon the board at some convenient place where it will not interfere with the drawing.

When there are lines of different widths to be

made, begin with the finest and ink all those of the same width before changing the pen.

Make all the lines of the geometrical problem figures of the same width, using that width shown as the standard for "Line of object (seen)," see Figure 53, on the following page.

Be very careful to make smooth lines, and to start and stop them exactly at the points intended.

First ink all circles. Where there are a number of concentric circles, begin with the smallest and work out to the largest. Then ink arcs, and irregular curves in the order named, because it is easier to draw straight lines tangent to curves than to do the reverse.

Ink intersecting arcs a very short distance—about 1/8 in. only—on each side of the point of intersection.

All lettering is to be done in black, with a writing pen and in the prescribed style, using alphabets Nos. 1 and 2 shown in the plate of standard lettering. See Figure 41.

All ruled lines used in laying out the sheet, except the border and the lines that divide the space enclosed by the border into six equal rectangles are to be erased in finally cleaning the sheet and will therefore not be inked.

Make the border lines of the width specified for borders, as shown on the plate of standard lines.

Make the division lines separating the problems narrower than the border lines and wider than the lines of the problems—about half way between.

Each sheet must bear the name of the draftsman, date of beginning the drawing, date of finishing the same, and the number of hours occupied on it.

After inking the drawing it is to be carefully cleaned with a soft pencil eraser, and then submitted to the inspector for final examination. When approved by him it will receive his third signature and is then to be removed from the board and filed in the portfolio.

Never roll a drawing as that would spoil it, besides making it inconvenient to handle. In office practice drawings are filed away flat in shallow drawers.

GEOMETRICAL PROBLEMS 7 TO 12 INCLUSIVE.

Prepare a sheet for Problems 7 to 12 like that laid out for Problems 1 to 6. See Figure 50.

Just as soon as the draftsman has affixed his name and other required data he must present his drawing to the inspector for the latter's signature and stamp of date of starting the drawing.

After the drawing has been completed in pencil it must be again presented to the inspector for his signature showing acceptance of the constructive work.

After the drawing has been completed in ink it must be again presented to the inspector for his

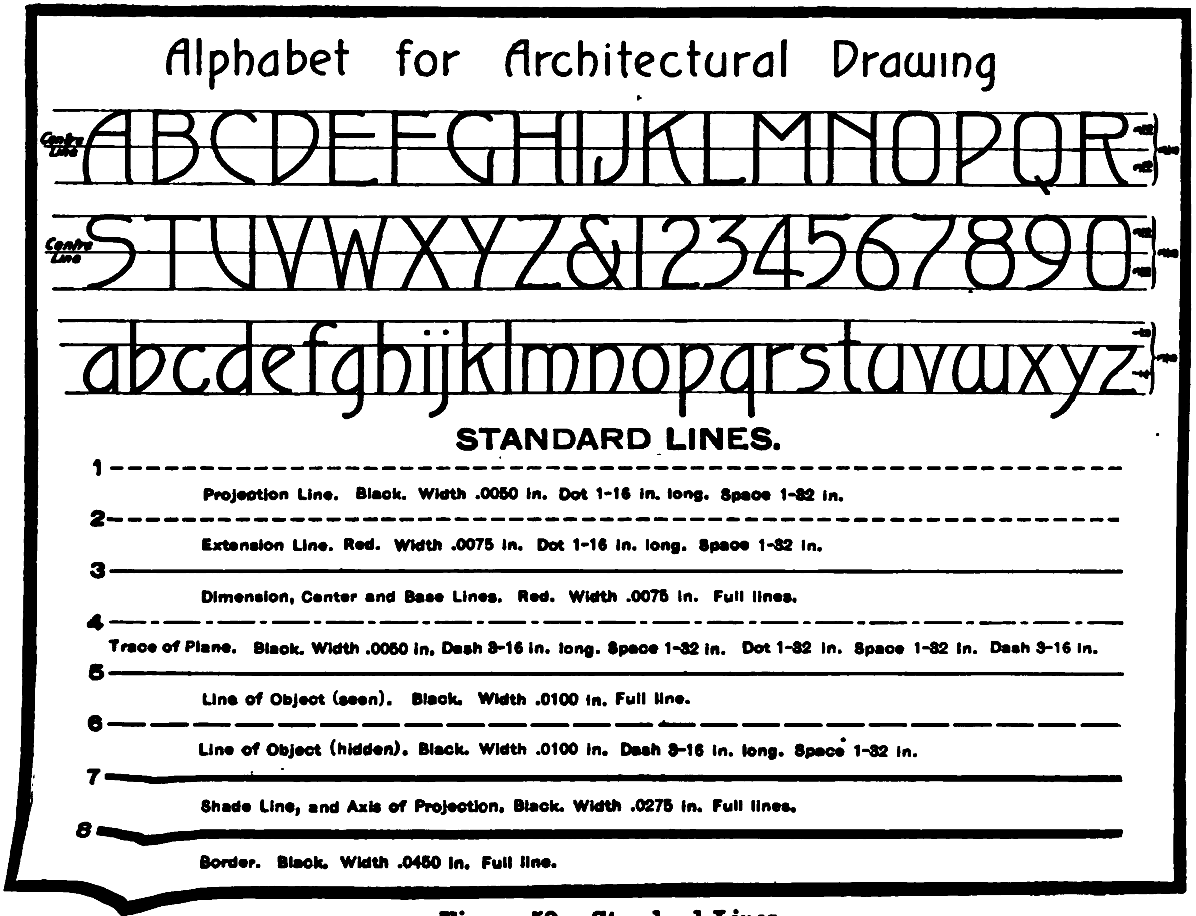


Figure 53.—Standard Lines.

signature showing his approval and acceptance of the sheet as being finished.

A similar course is to be followed with respect to the succeeding sheets.

PROBLEM 7.

To draw through a given point, a line parallel to a given line. 1st method.

Parallel lines are lines which lie in the same plane and do not meet however far they are prolonged in both directions. Any two parallel lines are everywhere equally distant. The distance between parallel lines is measured by the length of a perpendicular from one line to the other. The distance of a point from a line is measured by the perpendicular to the line extending from the point to the line. The method adopted here for the solution of the problem depends upon the statements just preceding, and the application of Problem 2 and Problem 1 of this series.

Construction:—Assume the given line and the given point, placing the line about ⅞ in. from the lettering lines and the point about ⅞ in. above the line and to the left of its center.

Erect a perpendicular to the given line which shall pass through the given point, using Problem 2. Consult the first sheet of drawing without fail. This perpendicular gives the distance of the point from the line. Choose a point on the given line at the right of the center of the line, and there erect a perpendicular, using Problem 1.

Obtain the distance of the given point from the given line—measured along the perpendicular—and lay it off from the line, along the second perpendicular. Through the point thus determined, and the given point, draw a line and it will be the required parallel to the given line.

See that the figure is of such shape and dimensions, and so placed as to nicely fill the space assigned for it. Letter the problem carefully and thoroughly, continuing the letters alphabetically from the preceding sheet of problems.

Draftsman's method:—Place the triangles as explained in Problem 1 and shown in Figure 52. Use them in a similar way, but draw along that side of the first triangle which is adjusted to the given line.

PROBLEM 8.

To draw through a given point, a line parallel to a given line. 2nd method.

On a piece of sketch paper draw two parallel lines, and across them at any angle draw another straight line.

This intersecting line is called a **transversal**—meaning, turned across.

The angles thus formed, lying between the parallels, and included between the parallels and the

transversal—four in number—are called **interior angles.**

The angles lying on opposite sides of the transversal and which are not adjacent, that is, do not have the same vertex, are called **alternate angles.**

If two parallel straight lines are intersected by another straight line, the alternate interior angles are equal.

The converse or opposite of the foregoing statement is also true, that is to say: if two straight lines are cut by a third straight line so as to make the alternate interior angles equal, the two lines are parallel.

The solution of this problem depends upon the statements just made, and upon an application of Problem 6.

Construction:—Assume a given line and a given point similar to those of the preceding problem. Through the given point draw a line to any point of the given line.

The construction line just drawn is to act as a transversal. The figure looks better if the transversal is oblique to the given line.

On the opposite side of the transversal, and using the given point as the vertex, lay off an angle equal to the acute angle which the transversal makes with the given line, according to the method employed in Problem 6. Produce (that is, continue) the side of the angle just made to be of about the same length as the given line, to which it is the parallel required.

Draftsman's method:—Same as for Problem 7.

PROBLEM 9.

To bisect a given angle.

In Problem 5 it was seen that the bisector of an arc passes through the center of the circle. Problem 9 depends for its solution directly upon Problem 5.

Construction:—Assume the given angle. It may be of any shape, but assume it to be an acute angle.

Place it about midway of the space with the vertex at the left, and let it be large enough to fill the space nicely. With the vertex as a center, and using a radius of about two-thirds the length of either side, draw an arc across the sides.

Bisect the arc just drawn. The bisector passes through the points where the arcs of construction intersect. It will be found to pass also through the vertex of the angle if the drawing has been nicely executed. The intersecting construction arcs on the side next the vertex might therefore have been omitted and the bisector drawn directly from the outside intersecting arcs to the vertex of the angle.

This point should be remembered for future constructions, but in this problem it is desired that the complete construction should be shown.

Draftsman's method:—Use the geometrical method. Or a protractor may be employed.

PROBLEM 10.

To construct a triangle when the three sides are given.

A triangle is a polygon bounded by three straight lines. See Figures 54, 55 and 56.

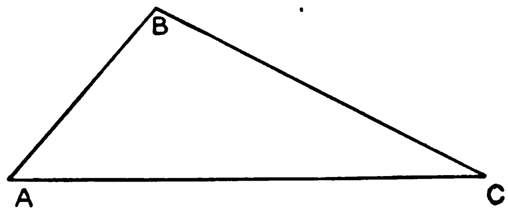


Figure 54.
Scalene Triangle.

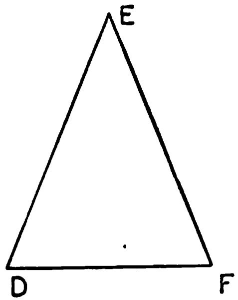


Figure 55.
Isosceles Triangle.

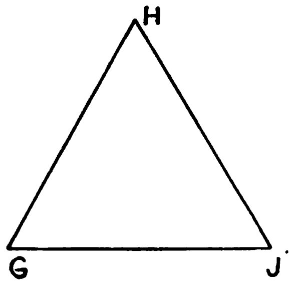


Figure 56.
Equilateral Triangle.

A polygon is a portion of a plane bounded by straight lines.

The bounding lines of a triangle are called the **sides** of the triangle. The sum of the sides is called the **perimeter** of the triangle. The angles formed by the sides are called **angles** of the triangle, and the vertices of these angles are called the **vertices of** the triangle.

A triangle is called with reference to its sides, a **scalene triangle,** when no two of its sides are equal, see Figure 54; an **isosceles triangle,** when two of its sides are equal, see Figure 55; an **equilateral triangle,** when its three sides are equal, see Figure 56.

A triangle is called with reference to its angles, a **right triangle,** when one of its angles is a right angle, see Figure 57; an **obtuse triangle,** when one of its angles is an obtuse angle, see Figure 58; an **acute triangle,** when all three of its angles are acute angles, see Figure 59; and an **equiangular triangle,** when its three angles are equal, see Figure 60.

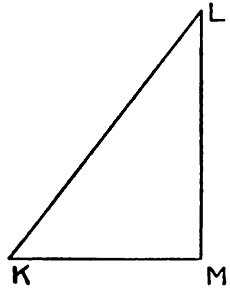


Figure 57.
Right Triangle.

In a right triangle, the side opposite the right angle is called the **hypotenuse,** and the other two sides are called the **legs,** of the triangle.

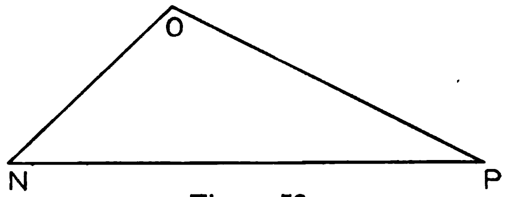


Figure 58.
Obtuse Triangle.

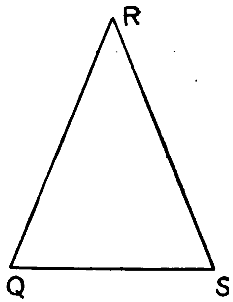


Figure 59.
Acute Triangle.

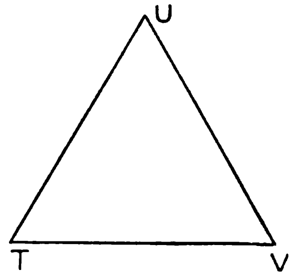


Figure 60.
Equiangular Triangle.

The side on which a triangle is supposed to stand, is called the **base** of the triangle. In an isosceles triangle, the equal sides are called the legs, and the other side, the base; in other triangles, any one of the sides may be taken as the base.

The angle opposite the base of a triangle is called the **vertical angle,** and its vertex, the **vertex** of the triangle.

The **altitude of a triangle** is the perpendicular distance from the vertex to the base, or to the base produced (extended).

The three perpendiculars from the vertices of a triangle to the opposite sides (produced if necessary) are called the **altitudes**; the three lines bisecting the angles are called the **bisectors**; and the three lines from the vertices to the middle points of the opposite sides are called the **medians** of the triangle.

Every triangle consists of six parts, namely: three sides and three angles. If any three of these parts are given—except in the case of the three parts being all angles—the triangle can be fully determined and constructed.

Construction:—Assume three lines for the lengths of the given sides. For convenience let the shortest of these given lines be not less than 1¾ in. and let the longest not exceed 2¾ in.

Make the given lines horizontal. Place them about ¼ in. below the head line of the problem, and about ¼ in. apart. About ⅜ in. from the lettering lines draw an indefinite line, preferably horizontal, and on it lay off a distance equal to the length of one of the given sides.

For the sake of uniformity let this length be that of the longest side. Next set the compasses to the length of a second given line or side and from the

left extremity of the side just laid off, strike an indefinite arc. Set the compasses to the length of the third side and from the right extremity of the side first laid off, strike a second arc intersecting the one last drawn.

Connect this intersection with the extremities of the side first laid off and the figure so formed is the required triangle.

Draftsman's method:—None. Use the geometrical method.

PROBLEM 11.

To construct a triangle when two sides and the included angle are given.

Construction:—Assume two lines, the shorter to be not less than 1¾ in. long, placing them towards the upper left corner of the rectangle. Then assume an angle, placing it towards the upper right corner of the rectangle.

This angle may be of any shape, but for uniformity and good appearance of the drawings, let it be an acute angle.

Just above the lettering lines assume a line upon which to construct the triangle. From either extremity of the line (but let the right extremity be used), lay off a distance equal to either of the given sides (use the longer), of the required triangle. At either extremity (use the left), of the distance so laid off, construct an angle equal to the given angle (Problem 6).

Produce (that is, extend), indefinitely this side of the angle just made, and from the vertex lay off along the side a distance equal to the second of the given sides of the required triangle.

Connect this extremity of the second side just determined, with the unattached extremity of the side first laid off and the figure thus formed is the required triangle.

Draftsman's method:—None. Use the geometrical method. The protractor may be used to lay off the given angle.

PROBLEM 12.

To construct a triangle when one side and the two including angles are given.

Construction:—Assume two angles for the given angles, placing them towards the top of the rectangle. These angles may be any shape—that is, acute or obtuse—provided their sum is not equal to or more than two right angles. This is so because the sum of the three angles of a triangle is always equal to two right angles, as the pupil will learn in more advanced geometry. For this problem let the pupil assume both the angles as acute angles of medium size and not of equal size nor yet differing greatly. Below the angles, assume a line for the given side. This line may be of any length, but for this drawing let it be between 2¾ in. and 3 in. long.

Just above the lettering lines draw an indefinite

line. From either extremity (use the right), lay off a distance equal to the length of the given side. At one end of this distance lay off an angle equal to one of the given angles, producing the side indefinitely, and at the other end construct an angle equal to the remaining given angle, also producing its side indefinitely. These sides sufficiently produced will intersect in a point and the figure thus formed will be the required triangle.

Draftsman's method:—None. Use the geometrical method. The protractor may be used to lay off the given angles.

GEOMETRICAL PROBLEMS 13 TO 18 INCLUSIVE.

PROBLEM 13.

To pass a circumference through three given points.

Construction:—Assume three points for the given points. They may have any position except that they must not be in a straight line. For this problem, however, let one point be placed $1\frac{1}{4}$ in. from the upper border of the rectangle and an equal distance from the left border. Place another point about 1 in. to the right of and a little above the point previously located. Place the third point about $1\frac{1}{4}$ in. below the one first made. Since a circumference is to be made to pass through these points, straight lines joining them would become chords of that circumference. Draw such lines connecting the middle point with the ones on either side.

In Problem 5 it was found that the bisector of an arc bisects the chord of the arc, and passes through the center of the circle of which the arc is a part.

Apply this to Problem 13. Bisect the chords formed by joining the given points, using Problem 4. Produce the bisectors till they intersect. Since both the bisectors pass through the center of the circle and their point of intersection is the only point they have in common, that intersection must be the center of the required circle and circumference. Using this point as a center, and a radius reaching to one of the given points, strike a circumference. It will pass through each of the three given points if the problem has been accurately drawn.

Draftsman's method:—The geometrical method would probably be used. Otherwise bisect the chords with the scale or dividers and erect perpendiculars with the triangles. See Problems 4 and 1.

PROBLEM 14.

To draw a tangent to an arc at a given point on the arc.

The word tangent comes from the Latin word meaning to touch. A **tangent** is a straight line which touches a circumference but will not inter-

sect it however far produced; as B C in Figure 61. The point in which the tangent touches the circumference is called the **point of tangency**, or **point of contact.**

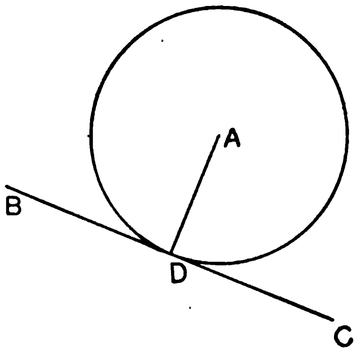


Figure 61.
Tangent.

In Figure 61, D is the point of tangency. A tangent is always perpendicular to the radius drawn to the point of tangency. Thus in Figure 61, A D B and A D C are right angles and A D is perpendicular to B C. Upon this fact depends the construction of this problem.

Construction:—Assume the given arc, and the point upon the arc at which it is desired to construct a tangent—the point of tangency.

Draw a radius from the center from which the arc was struck, to the point of tangency, and at the latter point construct a perpendicular by Problem 3. This perpendicular is the required tangent. Notice that the angle formed by the radius and the tangent is a right angle, and is inscribed in the semicircle used in constructing the problem.

An inscribed angle is one whose vertex lies in the circumference of a circle and whose sides are chords of that circle. An angle inscribed in a semicircle has a diameter for its longest side and is always a right angle.

Draftsman's method:—The same as that for Problem 3, and explained in Problem 1.

PROBLEM 15.

To draw a tangent to an arc from a given point outside the arc.

Construction:—Assume the given arc and the given point outside the arc from which it is desired to construct a tangent to the arc. Draw a line connecting the given point and the center point from which the arc was struck. Bisect this connecting line (Problem 4), and from its middle point as a center, and with a radius reaching to either of its extremities strike an arc cutting the given arc.

The point in which the given arc is thus cut will be the point of tangency sought, and a line joining this tangent point and the given point will be the required tangent.

This fact will be made evident by drawing a radius from the point of tangency to the center from which the given arc was struck. Draw this radius.

It will be seen that the tangent, the radius, and the line joining the given point with the center of the given arc form a right angled triangle. This triangle is right angled at the point of tangency, because the angle at that point is an inscribed angle since its including sides—the tangent and the radius—are chords of the construction circle, and its opposite side or hypothenuse is the diameter of the construction circle. Review Problem 14.

Draftsman's method:—Adjust a straightedge so that a line may be drawn along it passing through the given point and just touching the circle. If the point of tangency is desired, adjust the triangles as shown in Figure 52, Problem 1, and erect a perpendicular to the tangent which shall pass through the center of the given arc. This is an application of Problem 2.

PROBLEM 16.

To draw an arc of given radius tangent to two intersecting lines.

The two given intersecting lines form an angle. Since the given arc is to be tangent to each of the sides of this angle, its center must lie within these lines. It must also be equidistant from the lines and will lie somewhere upon the bisector of the angle. Also since the arc is to be tangent to both of the lines the radius of the arc will be perpendicular to either line at some point of the line, and the center of the arc must be distant from that line an amount equal to the given radius. The center will, therefore, lie somewhere on a line parallel to the side in question, and since it lies both on this parallel line and on the bisector of the angle, it must be at the intersection of these lines, because their point of intersection is the only point they have in common. The work to be done then, is to find the point of intersection of the bisector of the angle and of a line parallel to one of the sides of the angle and distant from that side an amount equal to the given radius of the required arc.

Then use this point of intersection so found, as a center and strike from it an arc having the given radius, which will make the arc tangent to the sides as required.

Construction:—Assume the given intersecting lines. The angle so formed may be of any size, but in this case let it be an acute angle, about half way between 30° and 45°, placed with its apex at the left, and having sides long enough to fill the space nicely.

Also assume a line for the given radius. To correspond with the general dimensions of the figure the given radius may in this instance be about ¾ in. long. Place it above the apex of the angle near the heading of the problem.

Bisect the angle formed by the intersecting lines. This is an application of Problem 9.

Then construct a parallel to one of the given intersecting lines. For the sake of uniformity in the work, use the lower line. Erect two perpendic-

ulars to the line, one near each extremity, by the method explained in Problem 1. Lay off on each perpendicular a distance equal to the given radius of the required arc, and through the points so found, draw a line and it will be the parallel line desired.

Use the point of intersection of the bisector and the parallel line as a center, and with the given radius strike the required arc. It will be found tangent to the given intersecting lines as required.

Draftsman's method:—If the given intersecting lines are very long and the given radius is quite large so that a very large figure results, the geometrical method explained may be used.

Another method is to draw parallel lines to each side and their intersection will also give the desired center from which to draw the arc.

In ordinary drafting work, however, the usual radius is quite small and the draftsman having set his compasses to the desired radius will find the proper center by judgment and a few trials.

PROBLEM 17.

To inscribe a regular hexagon in a given circle.

A hexagon is a polygon bounded by six straight lines. For a definition of polygon see Problem 10.

A regular polygon is a polygon which is equilateral and equiangular; as, for example, a square.

An inscribed hexagon (or other polygon), is one whose vertices lie in the circumference of a circle and whose sides are chords of that circle.

It is a property of the regular hexagon that its sides are each equal to the radius of a circle in which the hexagon can be inscribed.

Therefore having the circle given, to find the regular hexagon that can be inscribed therein it is necessary only to lay off the radius as a chord six times in succession along the circumference.

Construction:—Assume the given circle making its diameter somewhere between 2 in. and 2¼ in.

Beginning at any point of the circumference, as, for instance, the lowest or nearest point—which determine by the T-square and triangle and use in this problem—lay off along the circumference six chords each equal to the radius of the circle.

The figure so formed is the regular inscribed hexagon desired.

Draftsman's method:—By connecting the opposite vertices of the regular hexagon it will be seen that these diameters of the hexagon divide it into six equal equilateral and equiangular triangles. Each of the angles thus formed at the center of the circle is therefore 60° in size and each of the angles of the hexagon is 120°.

The sides of the hexagon, if the figure has two of its sides vertical or horizontal, can be drawn with the thirty-by-sixty triangle, or the T-square, or by these two instruments in combination. Place the triangle against the T-square so that the hypothenuse

crosses the center of the circle. Mark the points where the diameters that might then be drawn, would cut the circumference of the circle. These points are the vertices of the hexagon. Four sides of the hexagon may be drawn by use of the triangle in combination with the T-square, and the remaining sides may be drawn with the same combination of tools, or by the T-square alone depending upon the position of the hexagon.

PROBLEM 18.

To inscribe a regular triangle in a given circle.

Construction:—Proceed as in Problem 17, but instead of joining the consecutive points, join three of the alternate ones.

Draftsman's method:—Use the T-square and the 30x60 triangle.

GEOMETRICAL PROBLEMS 19 TO 24 INCLUSIVE.

PROBLEM 19.

To circumscribe a regular triangle about a given circle.

A circumscribed triangle (or other polygon) is one whose sides are all tangents to the same circle.

Construction:—Assume a circle for the given circle, *making it of* about 1⅜ in. diameter. Place its center 1⅛ in. above the lettering lines and in the center of the rectangle measuring from right to left.

Mark the lowest or nearest point of the circle, and lay off along the circumference two other points equidistant from each other and from the point first placed on the circumference (Problem 18).

Construct tangents to the circle at these three equidistant points (Problem 14.) The first point to be used in constructing each tangent is best placed within the given circle. Prolong these tangents till they intersect, thus forming a triangle.

The work of construction must be very accurately done or the triangle will not be equilateral as required. Compare the sides of the triangle to see that they are all of equal length.

Draftsman's method:—The T-square and the 30x60 triangle may be used when the required circumscribing triangle is to be in the particular position specified in this case, that is, when the point of tangency for one side of the triangle is to be so situated that the radius to the point of tangency is a vertical line. In such case the tangent itself will be a horizontal line and may be made with the T-square. The remaining sides of the circumscribing triangle may be made by using the 30x60 triangle in combination with the T-square.

For any position in general of the required circumscribing triangle, use the 45, and the 30x60 triangles placed together. Put a point at any place on the circumference of the given circle at which it

is desired to have a side of the required circumscribing triangle tangent.

Beginning at this point, divide the circumference into three equal parts by means of the dividers or by use of the compasses (Problem 18), and then draw radii to the three points just determined.

Adjust the two drawing triangles as explained in the draftsman's method for Problem 1, see Figure 52, to a radius reaching to one of these points in the circumference. Slide the triangle which is in contact with the radius and draw a perpendicular to the radius, thus making a tangent to the circle, and it will be a side of the required circumscribing triangle.

In a similar way draw tangents at the other two points on the circumference and the required circumscribing triangle will be completed.

PROBLEM 20.

To inscribe a circle in a given triangle.

An inscribed circle is one whose circumference touches each of the sides of a polygon but does not intersect them.

Construction:—Assume any triangle for the given triangle. Let the base be horizontal and placed ⅜ in. above the lettering lines. Use a scalene triangle rather than an equilateral or isosceles triangle, as it is desired to show that the construction here given will apply to the most irregular triangle and therefore to any triangle.

Use good taste and judgment in making the triangle fill nicely the space available.

Since the circle is to be inscribed in the triangle, certain parts of the circumference, that is certain arcs, will be tangent to the sides of the triangle. The problem, therefore, somewhat resembles Problem 16, which problem should be carefully reviewed. Bisect each angle of the triangle (Problem 6) and produce the bisectors till they intersect. This point of intersection will be the center of the required circle.

Using a radius that will just reach any one of the sides of the triangle, strike a circle. It is the required inscribed circle and should be tangent to each of the sides of the triangle.

Draftsman's method:—Use the geometrical method.

PROBLEM 21.

To circumscribe a circle about a given triangle.

A circumscribed circle is one whose circumference passes through all the vertices of a polygon.

Construction:—Any triangle may be assumed for the given triangle, but to show that this solution is applicable to any triangle, use for this problem a scalene triangle, but make it with the sides not very unequal.

Since the circle is to be circumscribed about the triangle, the vertices of the triangle will lie in the circumference and the sides of the triangle will be-

come chords of the circle. The problem then is to pass a circumference through the three vertices of the triangle. It is very nearly a repetition of Problem 13, and the solution is to be made by an application of that problem.

Draftsman's method:—Use the geometrical method; or the scale or dividers and the triangle as suggested in the draftsman's method for Problem 13.

PROBLEM 22.

To divide a given line into any required number of equal parts.

The solution here given will suffice to divide a line into any number of equal parts, but in this instance let it be desired to divide the line into six equal parts.

Construction:—Midway of the rectangle in which the drawing is to be placed, assume the given line. Let it be about 3 in. long and slightly inclined. Through one end of it draw a line of indefinite length to make any angle with the given line. The problem will look better in the present instance if the angle is made acute and of rather less than medium size. Through the other end of the given line, draw another line of indefinite length parallel to the second line, in the opposite direction and on the opposite side of the given line (Problem 8.) On each of the parallel lines thus formed, lay off from the vertices of the angles, the same number of equal spaces of any size.

Let there be in this instance six 7/16 in. spaces on each line. Connect the first point on one parallel (the extremity of the given line), with the last point on the other parallel, that is, the further end of the last space. Connect the second point on the first parallel with the next to the last point on the second parallel, and so on, thus forming a series of parallel lines which will divide the given line into equal parts as required. Be sure to letter the points in which the parallel lines cut the given line to indicate the required equal spaces into which the given line is divided.

Draftsman's method:—Use the scale if the line is of such length that this can easily be done. Otherwise use the bow dividers or hairspring dividers, and find the equal divisions by repeated trials of stepping along the line with the instrument set to the correct space as nearly as can be judged readily by the eye.

PROBLEM 23.

To construct a regular pentagon upon a given line as a side.

A pentagon is a polygon bounded by five sides.

A regular pentagon is one having equal sides and equal angles.

Construction:—For the given line assume a horizontal line 13/16 in. long. Place it 1 1/16 in. above the lettering lines and midway of the rectangle from left to right. With a radius equal to the length of the line, and with the left end of the given line as

a center, strike a circle. With the same radius strike another circle from the right end of the given line as a center. With the same radius and from the lower point of intersection of the first two circles as a center, strike an arc, cutting the first two circles and passing through the extremities of the given line. Let the arc approach but not touch the lettering lines. Draw a line to connect the points of intersection of the first two circles. From the lower points of intersection of the third circle with the first two, draw straight lines through the intersection of the third circle with the straight line just previously drawn. Stop these latter lines at their intersections with the farther sides of the first two circles and from these points as centers and with the same radius as before, strike short arcs intersecting outside the circles. Connect the point in which these arcs intersect, with the centers last used; and these latter centers with the extremities of the given line, thus forming the regular pentagon required.

Draftsman's method:—There are other methods of solving this problem, but the one here given will be found easy, accurate, not difficult to remember, is generally satisfactory and may therefore be used.

PROBLEM 24.

To copy a curve by points in equal, enlarged or diminished size.

As indicated in the statement of this problem, the method here explained will suffice to reproduce a curve in any desired proportion. In this instance let the curve be so reproduced that it shall be proportionally two-thirds the size of the original or given curve.

Construction:—Assume a curved line for the given curve. Theoretically any curved line may be assumed for the given curve, but in this instance obtain the curve from the hard rubber scroll or irregular curve. Use that part of the curve extending from A to B in the illustration, Figure 62, opposite.

Lay the irregular curve upon this figure and see what its general position is.

So draw the curve that its general direction from A to B or its center line from A to B if that should be made (which it need not be), would be horizontal and placed about $1\frac{1}{4}$ in. above the lettering lines.

Assume any straight line in a convenient position and at a convenient distance from the given curve for a base line. In this instance let the base line be horizontal and placed about $\frac{1}{4}$ in. above the lettering lines.

Through the left extremity of the curve draw a perpendicular to the base line by means of the T-square and triangle. From the point of intersection of this perpendicular and the base line, lay off along the base line any number of distances sufficient to reach to the other end of the curve, preferably making them equal in length for ease of construction.

Let each of these distances in the present instance

be ⅜ in. and from the points so fixed, erect, by means of the T-square and triangle, perpendiculars that shall cut the given curve.

If the curve changes direction rapidly at any part, in relation to the base line, as is the case at each extremity of the present curve, introduce intermediate perpendiculars midway between those already drawn.

In this figure draw two such intermediate perpendiculars, placing one in each of the extreme right and extreme left divisions of the base line.

Number each of the points of this construction, beginning with 1 so that the points may be easily distinguished from those of the reproduced curve.

The work of this problem so far explained results in having fixed a number of points on the curve in relation to an assumed line. A line passing through these points necessarily reproduces this curve exactly.

The problem now is to so place another set of points that through them a curve may be passed by means of the hard rubber scroll, with the result that a curve similar to the given curve but only two-thirds as large shall be determined.

Assume another horizontal line above the figure already made for the base line of the required curve.

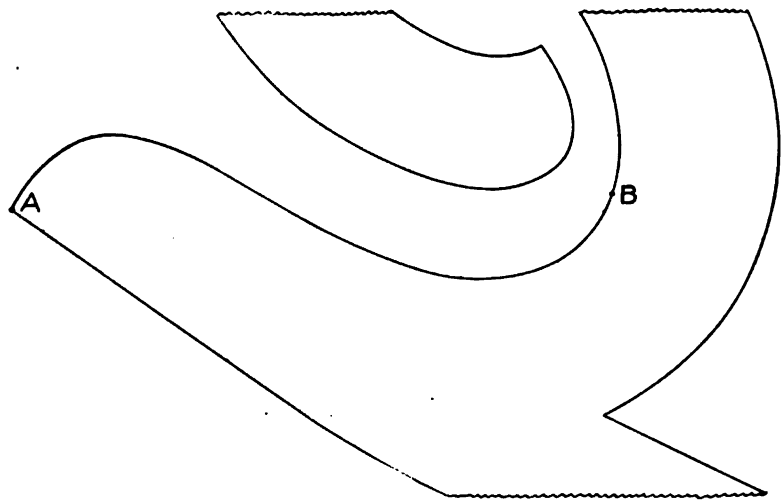


Figure 62.

Letter all the points of construction in this second figure as fast as made, beginning with A, regardless of previous problems.

Near the left end of this second base line erect a perpendicular by means of the T-square and triangle.

From the foot of this perpendicular lay off along the base line a number of equal distances to correspond with those laid off along the base line for the given curve.

Since the required curve is to be two-thirds the size of the given curve, these equal distances must be that proportion of the similar distances on the base line to the given curve.

Consult the scale and obtain from it the correct size of these required smaller equal distances. Lay them off along the second base line and by means of the T-square and triangle erect perpendiculars at the points so fixed. Cut off on these perpendiculars certain distances corresponding to those cut off by the given curve on the perpendiculars of the previous figure. These distances on the perpendiculars of the second figure must also be in the required proportion of two-thirds. Divide each of the perpendiculars of the first figure into three equal parts by means of the spring bow dividers and use two of these parts for the length of each respective perpendicular of the second figure. Through the points thus determined on the perpendiculars of the second figure draw a curve by means of the hard rubber scroll and it will be the desired curve. Since the dimensions of the second figure are two-thirds those of the first, that part of the scroll used in producing the first curve will not suffice to produce the second.

It will be found necessary to make the required curve in sections by fitting to the points last established such parts of the scroll respectively as will produce a curve passing through them.

Do not try to match a large number of points at the same time with any one part of the scroll. If a portion of the scroll is found that will match four points, draw enough of the curve to connect three points only.

Then find another part of the scroll that will answer to connect that point not drawn through and some additional points. In this manner breaks and abrupt changes of direction in the curve are avoided, and a smooth line is produced.

A skillful draftsman will in this way produce the most complex curve so smoothly that it will appear to be a continuous line made with one movement.

The method here explained is called establishing a curve by ordinates. The perpendiculars are called **ordinates.** The base line is called an **axis of ordinates.**

This method should be remembered. It will appear again in this drawing course—in a slightly different form—and will also be of use in physics and geometry.

Draftsman's method:—Use the method just given.

PROJECTION DRAWING

Mechanical drawing is the necessary preliminary of all constructive work—at least of complicated work—in the mechanical arts. Such drawing has for its purpose to show a workman what to make, how to make it, and of what to make it.

A drawing made with these ends in view is called a working drawing.

A working drawing is a drawing rendered in conventional style and with such detailed information as shall make possible the accurate construction of the object represented without further particulars being given.

An example of a working drawing is given in Figure 63, also in Figure 64.

The information which a working drawing should give includes the true shape and dimensions of the object, and a statement of the materials to be used in its construction.

A working drawing should also state how the parts are to be finished and put together, where the methods to be employed are at all unusual or peculiar, and it would not be safe to presume that the workman would know what was wanted, without special directions.

Frequently a working drawing must also show not only the external appearance of the object, but its internal arrangement as well, in order that the fullest information shall be conveyed to the workman.

A drawing showing the internal arrangement of a valve is shown in Figure 64.

It is evident upon examination of a picture or photograph of some building or machine, that representative drawing will not answer for a working drawing.

In the first place, a representative drawing shows an object as it appears to the observer, and not as it really is. Consequently the information it conveys is not exact and truthful. Examine Figure 65, which represents a triangular prism whose two ends are equal and parallel and whose long edges are also equal and parallel.

Measurement of the drawing will show that the edges which are of equal length on the object, are not so in the drawing, although they may appear to be, nor are lines really parallel so represented.

Again the further side of the object does not show at all.

This deficiency would not prevent a person from

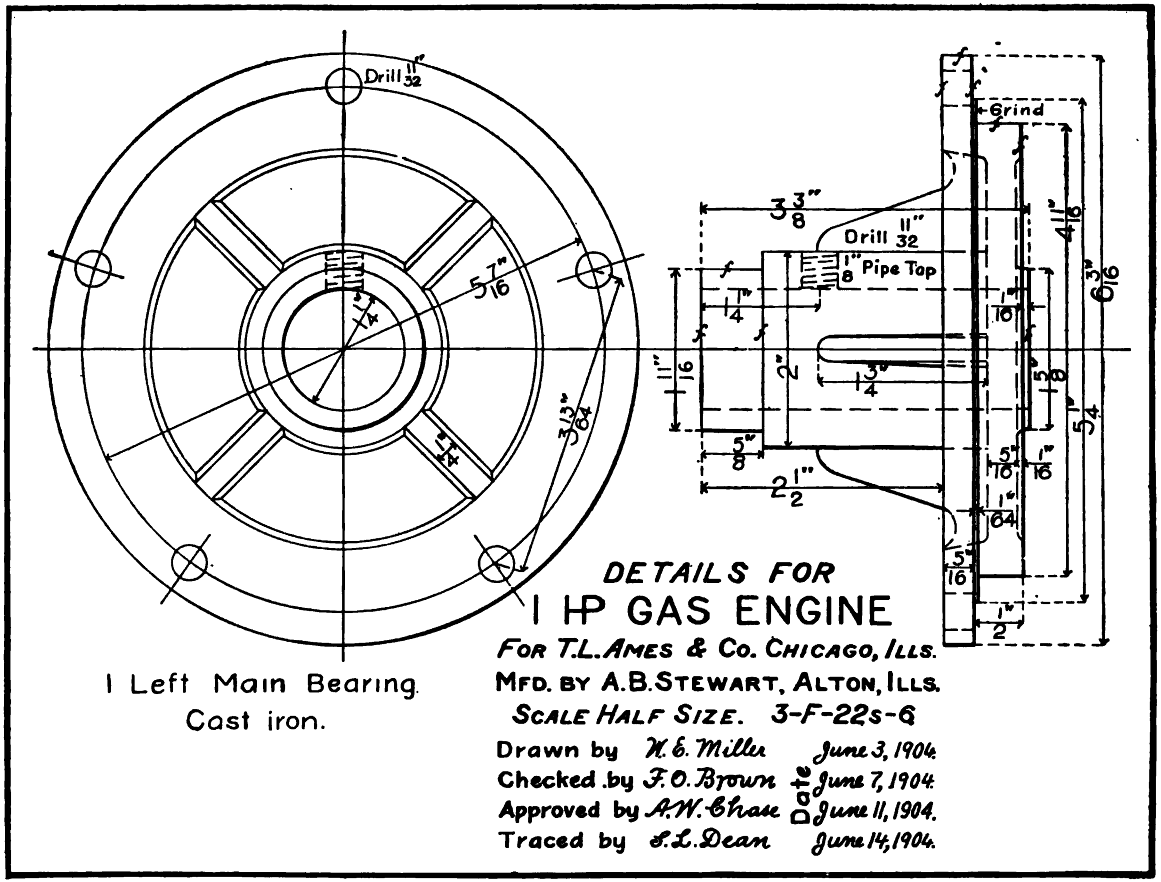
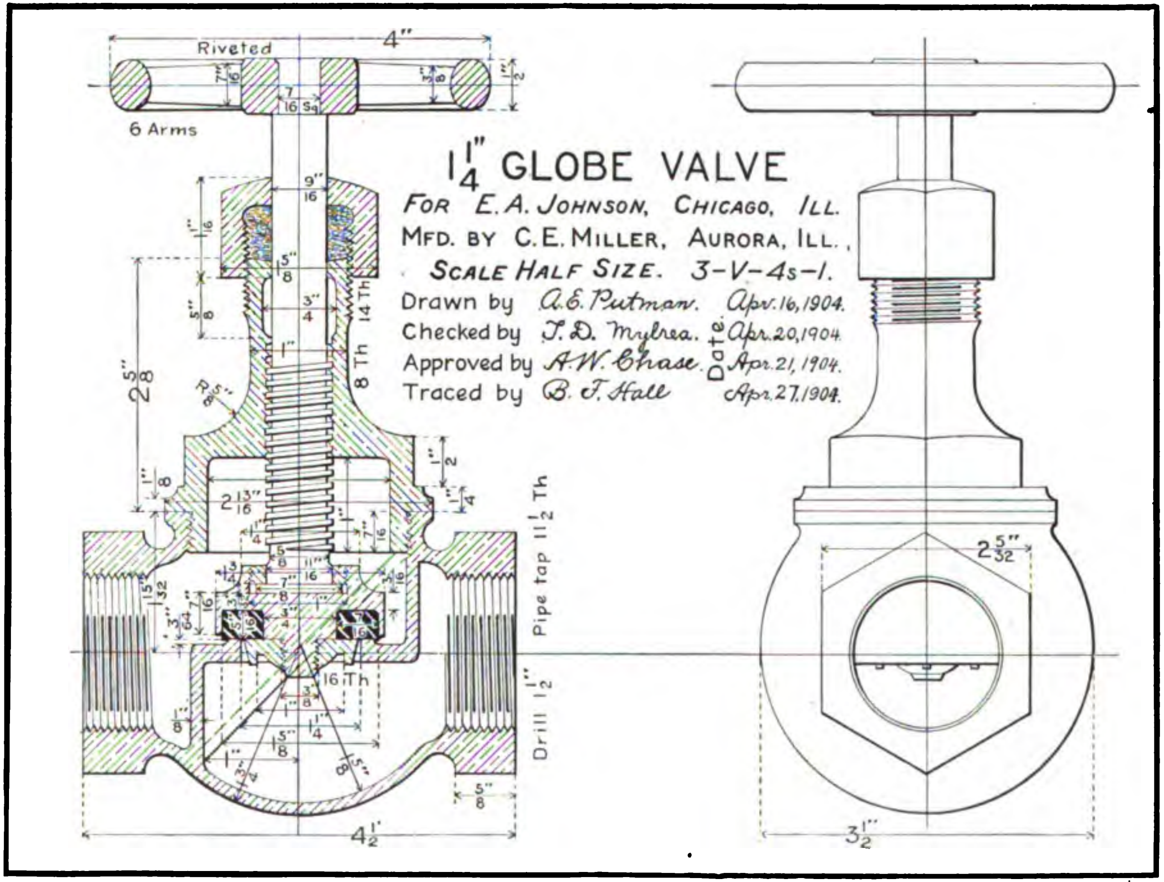

Drill 11/32"
Grind
Drill 11/32"
1/8" Pipe Tap
I Left Main Bearing.
Cast iron.
DETAILS FOR
1 HP GAS ENGINE
FOR T.L. AMES & CO. CHICAGO, ILLS.
MFD. BY A.B. STEWART, ALTON, ILLS.
SCALE HALF SIZE. 3-F-22s-6
Drawn by W. E. Miller June 3, 1904.
Checked by F. O. Brown June 7, 1904.
Approved by A. W. Chase June 11, 1904.
Traced by S. L. Dean June 14, 1904.
Date

Figure 63.



1 1/4" GLOBE VALVE
FOR E. A. JOHNSON, CHICAGO, ILL.
MFD. BY C. E. MILLER, AURORA, ILL.,
SCALE HALF SIZE. 3-V-4s-1.
Drawn by A.E. Putman. Apr. 16, 1904.
Checked by J. D. Mylrea. Apr. 20, 1904.
Approved by A.W. Chase. Apr. 21, 1904.
Traced by B. J. Hall Apr. 27, 1904.
Date.
Riveted
6 Arms
Pipe tap 11 1/2 Th
Drill 1 1/2"
8 Th
14 Th
16 Th

Figure 64.

fully understanding the simple prism here shown, but in more complicated objects a similar lack of

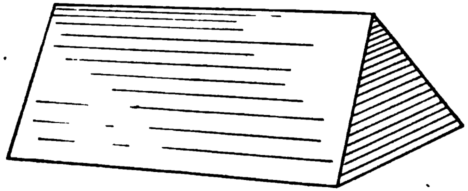


Figure 65.

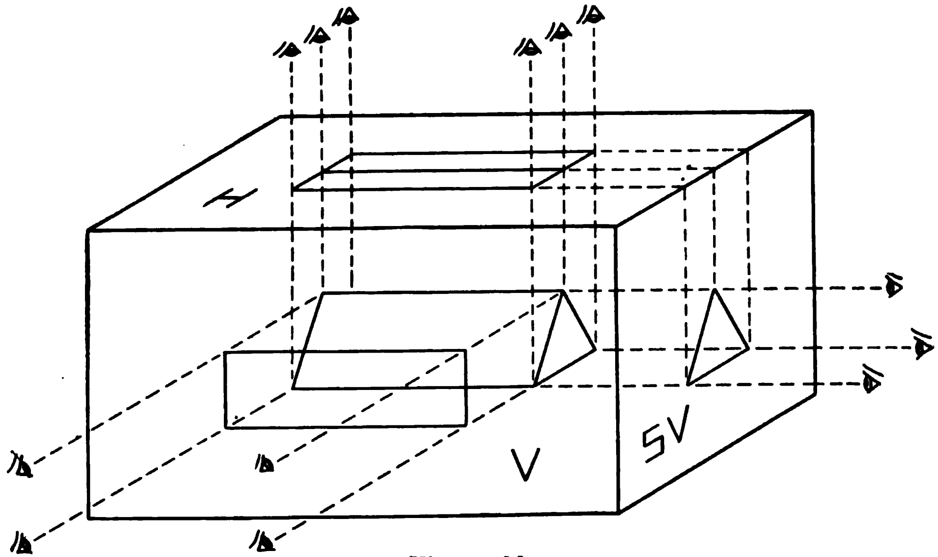


Figure 66.

information might make it impossible to construct the object correctly.

It is evident, then, that some clear, uniform, and logical system of representation differing in its nature from a mere picture, must be adopted and used by the draftsman in order that the workman may always understand what information the drawing is intended to convey. This system may be described as follows:—

The object is placed, or supposed to be placed, within the angle formed by three pieces of plane glass, hinged together and situated at right angles to each other. See Figure 66.

This apparatus may be made of three pieces of ordinary window glass fastened together by narrow strips of cloth glued to the edges of the glass. It is well to grind the surface of the glass where the glue is to be applied so that the glue shall hold better. Liquid fish glue will be found to answer well for this work.

The object being placed beneath or within these planes, the observer then looks through each plane

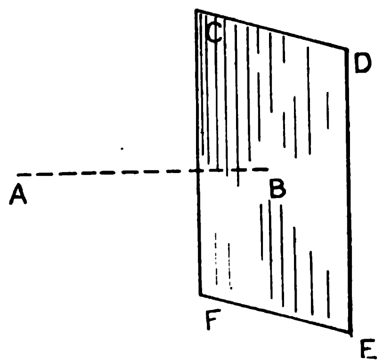


Figure 67.

and traces upon it the outline of the object as there seen. It should be noted that for this style of drawing the observer is supposed to be at an indefinite distance, in which case the rays of light reflected from the object to the eye and by means of which the object is seen, would all be parallel to each other and perpendicular to the plane in each case, for the observer is also supposed to assume three general positions from which to view the object—one opposite each plane.

The point in which a line passing through a given point perpendicularly to a given plane, pierces that plane, is called the **projection of a point** upon a plane, and the perpendicular line itself is called a **projection line.**

Thus in Figure 67, B is the projection of the point A upon the plane C D E F, and A B is the projection line.

Therefore in the case of the object beneath the planes, the rays of light by which the object is seen, coming to the eye from all points of the object and falling upon or piercing the planes of projection, form the projections of the object upon the planes. Hence this and similar methods of drawing are classed as projection drawing.

A projection drawing is the representation of an object upon a surface, made by the intersection with that surface, of lines from the point of sight to the object.

When the rays of light proceed in parallel lines perpendicular to the planes of projection, as in the case illustrated, see Figure 66, the representations found upon the planes of projection and included between the lines of projection, give the true details of the object both in form and dimensions. Hence this particular form of projection drawing receives the name of orthographic projection. The word

orthographic is derived from the Greek word orthos, meaning right, correct, or true; and grapho, meaning to write or draw.

Orthographic Projection is the art of representing an object upon two or more planes situated at right angles to each other, by the use of projecting lines perpendicular to the planes, in such a way as to show exactly the forms and dimensions of the parts of the object and their relations to each other.

The planes upon which the views appear are called the **Planes of Projection,** and the views of the object upon these planes are called its **Projections.**

After the projections of the object have been made, one of the planes—the front vertical plane—is assumed as the plane of the paper, and the other planes are revolved about their intersections with the first plane till they form one plane with it, and the views or projections are all situated on one surface, see Figure 68.

The lines in which the planes of projection meet—that is, their intersections—form after the revolution, two intersecting straight lines crossing at right angles. Of these two lines, the one from left to right is called the **Horizontal Axis of Projection** and the other is termed the **Vertical Axis of Projection.**

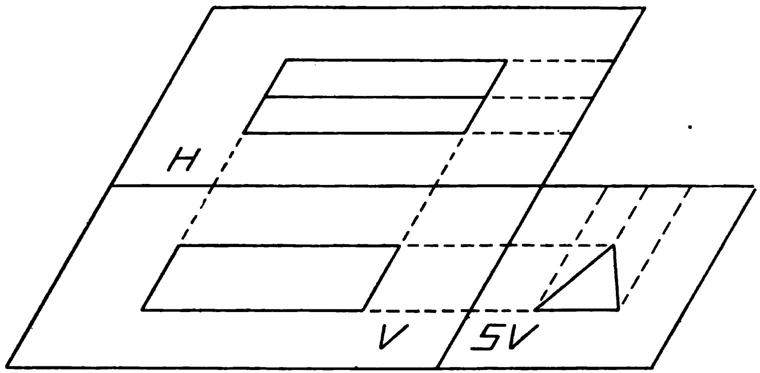


Figure 68.

The planes of projection are called from their respective positions, the **Horizontal Plane of Projection, the Front Vertical Plane of Projection** (or simply the **Vertical Plane),** and the **Side** (or **End**) **Vertical Plane of Projection.** These names are abbreviated for convenience, in the order given to **H,**

and **V**, and **SV.** The views or projections upon the planes are called (also in the same order) the **Top View** or **Plan,** the **Front View** or **Front Elevation** and the **Side** or **End View** or **Elevation.** After the revolution of the planes into the plane of the paper, the Top View is found in front and above the horizontal axis, the Front View is found in front and below the horizontal axis and the Side View is found below the horizontal axis and at one side or the other of the Front View according to the side or end selected to be represented.

In these problems in projection the right hand side will be represented in each case, and the view representing it should be placed horizontally at the right of the Front View.

PROBLEM 25.

Three views of a right rectangular prism $1\frac{3}{8}$ in. x 2 in. x $3\frac{3}{4}$ in. having its faces parallel in pairs to the planes of projection, the largest faces being parallel to V and the greater dimension of those faces vertical.

A polyhedron is a solid bounded by planes.

A prism is a polyhedron of which two opposite faces, called **bases,** are parallel polygons, and the other faces, called **lateral faces,** intersect in parallel lines, called **lateral edges.** The lateral edges are equal, the lateral faces are parallelograms, and the bases are equal

A parallelogram is a quadrilateral whose opposite sides are equal and parallel.

A quadrilateral is a portion or a plane bounded by four straight lines.

A rectangle is a parallelogram whose angles are all right angles.

A square is a rectangle whose sides are all equal.

The altitude of a prism is the length of the perpendicular between the planes of its bases.

Prisms are called **triangular prisms, quadrangular prisms,** etc., according as their bases are triangles, quadrilaterals, etc.

An oblique prism is a prism whose lateral edges are not perpendicular to its bases.

A right prism is a prism whose lateral edges are perpendicular to its bases.

A regular prism is a right prism whose bases are regular polygons.

The axis of a prism is a right line joining the center points of the bases of the prism.

Before commencing the mechanical drawing of Problem 25 each pupil is to make in his notebook four **freehand sketches** of the object. These sketches are to be in orthographic projection, not in perspective drawing, and are to be made with a soft pencil. They must be accepted and stamped by the inspector before the mechanical drawing is begun.

Be sure to make the sketches in the notebook. This agrees with practical work in well regulated drafting rooms, for there all original sketches, data,

and calculations are required to be made in books designed for the purpose and to be afterwards carefully preserved.

Also put in the notebook such other information, concerning drawing as may be given from time to time, if it is not already stated in this text. Put all notes and sketches in the notebook in regular order from the front of the book. If a mechanical engineer goes from his office perhaps to some machine shop or factory to obtain measurements for placing machinery, he will take down his measurements in a notebook for convenient and safe preservation.

A loose sheet of paper would be very easily lost or destroyed, therefore he uses a well-made blank-book, not only for outside work, but also for office sketches and calculations.

In a similar way, a civil engineer when in the field making a survey, keeps his data in a notebook or fieldbook. Draftsmen and engineers carefully keep these notebooks on file because they often prove of great value for reference at a later date.

To make the four sketches required for Problem 25, proceed as follows:—

Place the object beneath the glasses representing the projection planes and in the position specified by the statement of the problem. Then make three separate and distinct freehand sketches of the object and the planes of projection as seen from the three positions—one opposite each plane—as before explained. These three sketches are to be made upon one page of the notebook. They need not be in true or full size, but must be large enough to be quite clear, and must be neatly and carefully made. It is desired to ascertain through them what impression is conveyed to the pupil as he looks at the object from the different specified positions.

In these sketches the pupil shall for this problem alone, include not only the outlines of the object but also those of the projection planes. The sketch of a cone shown in Figure 69, will give the pupil a general idea of what is expected from him.

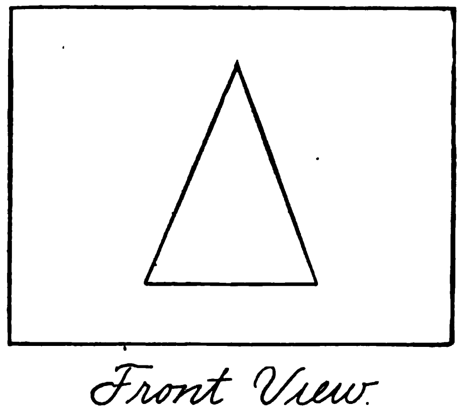


Figure 69.

Of these three sketches—First, the one made while viewing the projection planes and the object within them from a point above the planes, is the **Top View**, or **Plan**.

Put the name of the view below the sketch so that

the inspector may know that the pupil understands what he has drawn or attempted to draw. Notice how the front plane appears, or what it looks like in this top view, and decide how it should be represented in the sketch. Also see what the side plane looks like in the top view.

Second, the sketch made while viewing the planes and object from a point in front of them, is the **Front View**, or **Front Elevation.**

Put the name of the view below the sketch. See what the top plane looks like in this view. Also notice what the side plane looks like.

Third, the sketch made while viewing the planes and object from a point opposite the side plane, is the **Side View, or Side Elevation.**

Put the name of the view below the sketch. Notice what the top plane looks like in this view. Also see what the front plane looks like.

Each pupil is then to draw another sketch, the Fourth; a sketch showing the planes of projection revolved out into one plane, joined together as the glasses are, and each one bearing its own view of the object, properly placed with respect to the plane on which it appears, and to the adjoining plane and view.

The fourth sketch is to be made upon the next page of the notebook and is designed to show the pupil's idea of the relation of the views.

For this purpose, name the planes by placing upon each one its appropriate abbreviated name—**H**, or **V**, or **SV**—and near each view write its proper name.

PENCILING A PROJECTION DRAWING.

Problem 25.

To begin the mechanical drawing put the name of the draftsman in the usual place at the left end of the sheet, also place the date, pencil a border of the usual size, and submit the sheet to the inspector for a starting signature and date.

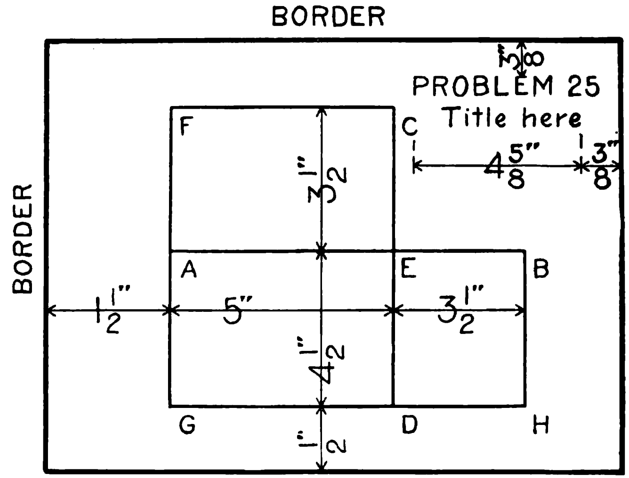


Figure 70.

Construction:—Draw the rectangles to represent the planes of projection, see Figure 70, using the measurements there given but not placing those dimension lines and figures upon the drawing because

they do not belong to the construction drawing but are given solely to enable the pupil to place his drawing nicely upon the paper.

Mark the three projection planes respectively **H**, and **V**, and **SV**, according to their positions. These letters designating the planes are to be vertical, ⅜ in. tall, and geometric in style. See alphabet No. 3, plate of standard lettering, Figure 41. They are to be placed within the outlines of the planes, but so as to be outside of the outlines of the object when these latter shall have been drawn.

Letter the horizontal axis of projection A B, placing the letter A at the left end of the line. Letter the vertical axis C D and the intersection of the axes E. These points should be similarly lettered in each of the succeeding problems as long as the axes are used. Make each letter designating a corner of the projection planes, a capital, ⅛ in. tall, in regular freehand shape, and placed uniformly 1/16 in. below and to the right of the point to which it belongs.

Where as in this case several letters are situated along the same line, even although widely separated, horizontal lettering lines should be drawn so that the letters may be similarly placed and of equal height.

Complete the lettering of the planes of projection as shown in Figure 70.

Next draw the views of the object. Centrally upon **H**, the horizontal plane of projection, lay off a rectangle to represent the top view of the prism.

Since the rays of light from the object to the eye, forming the projection lines are parallel, they must be as far apart where they pierce **H** as where they start from the object, and therefore the rectangle drawn on **H** to represent the top of the prism will have the same dimensions as the top of the prism itself. Letter the rectangle according to the following method. Call the upper front left corner of the prism—that is, of the object itself—J; call the upper back left corner, K; and the upper back and front right hand corners L and M respectively. Every point of an object must be represented on each of the three planes of projection.

The three projections of any point must be so lettered as to show that they represent the same point but are different views of it.

To accomplish this, each view of every point of an object will be designated by a letter to which is attached an appropriate subscript. Thus the representation on **H** of any point will be designated by a letter bearing the subscript $_T$; as J_T, meaning top view of J, in which $_T$ is the **subscript** and so called because it is written below the main letter. The same point will be represented on **V** by the same letter having the subscript $_F$, as J_F, meaning front view of J; and on **SV**, by that letter bearing the subscript $_S$; as J_S, meaning side view of J. Every letter used to designate a point of the object

is to be a freehand capital, 1/8 in. tall and placed uniformly 1/16 in. below and 1/16 in. to the right of the point which it designates unless some part of the drawing prevents, in which case it is to be placed as nearly as may be in the position just specified and yet not in contact with the interfering part.

In all cases these letters are to read vertically from the bottom of the sheet. That is, if the figure is inclined, it will not influence the letters to make them inclined also. They must be upright.

Draw lettering lines for these letters so that they may be of uniform height and regular placing. Make the height of each subscript letter one-half of the height of the letter to which it is attached. Place it to the right of and one-half of its height below the bottom of the letter to which it is attached.

These letters do not indicate at all the order in which the views must be made. They are used wholly to distinguish one view of a point from another view of it.

Sometimes a drawing is started on one plane of projection and sometimes on another.

When a letter is mentioned and no subscript is given, it is understood that the point itself—on the object—is being discussed.

When two or more points of the object are represented at the same place on the drawing, this fact may be shown by the use of a corresponding number of letters affixed and written in a horizontal line, it being understood that the left hand letter on the drawing designates that point on the object nearest the observer.

Corresponding to the foregoing directions the rectangle just drawn to represent the top view of the prism which is being drawn will be lettered $J_T K_T L_T M_T$, J_T being placed at the front left corner and the other letters being placed in regular succession, passing around the rectangle in the direction in which the hands of a clock move.

Designate the remaining corners of the prism as N, O, P, and Q; N being directly below J, O below

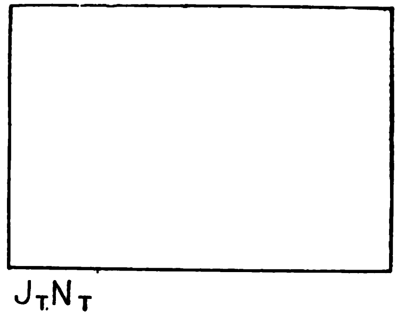


Figure 71.

K, P below L, and Q below M. Therefore at the left front corner of the rectangle on **H** the letters will appear as shown in Figure 71.

Complete the lettering of the rectangle in a similar way.

Next draw the front view, lettering it as fast as

completed, as was done on the geometrical problems. From the top view drop vertical dotted lines across the plane **V.** These lines are called **projection lines.** See plate of standard lines, Figure 53. They represent the projections on **H** and **V** of rays of light from the object to the eye. In this instance they determine the width of the front view. Complete the front view by outlining the height. In any convenient position (that is, ordinarily, but in this work where the size of the paper is fixed and the room available for the drawing is limited, aim to have equal spaces above and below the object), draw the horizontal line N_FQ_F, representing the lower front edge of the prism. Three and three-quarters inches (3¾ in.), the altitude of the prism, above N_FQ_F, draw a parallel line J_FM_F. Complete the front view by drawing the full lines N_FJ_F and Q_FM_F, and placing the letters representing the rear corners of the prism.

Next draw the side view. Extend the lines N_FQ_F and J_FM_F by dotted lines across **SV.** These lines determine the height of the side view, which must equal that shown in the front view.

The thickness of the object is already shown by the lines J_TK_T and M_TL_T, in the top view and may be transferred from there to the side view. By referring to the glasses or transparent planes, it will be seen that any point of the object is, in the top view, as far distant from the horizontal axis of projection as in the side view it is distant from the vertical axis of projection.

Extend dotted lines—projection lines, representing the projections of rays of light from the object to the eye—from M_T and L_T parallel to the horizontal axis of projection, until they intersect the vertical axis of projection. With the distances of these projection lines from the horizontal axis as radii, and the intersection of the axes as a center, strike quadrant arcs continuing the projection lines from their intersections with the vertical axis, around to the horizontal axis. From the points where these arcs terminate against the horizontal axis of projection, drop vertical dotted projection lines across **SV.** The last lines, by their intersections with J_FM_F and N_FQ_F produced, will give the outline of the prism in the side view which should be lined in and the proper letters affixed to designate the rear or hidden face as seen in the side view.

SHADE LINES.

The views should next be shade-lined, an operation based upon the effects of light and shade and intended to give to the drawing an appearance of that solidity which the object in fact has. Light is assumed to fall upon the object from above and from the left, following the diagonal of a cube whose faces are parallel in pairs to the planes of projection. See Figure 72.

Notice that the **diagonal of a cube** extends from

one corner of the solid to the extreme opposite corner, and is much longer than the diagonal of a face, which latter extends only from one corner of a face to the opposite corner of the same face. The projection of this diagonal would in each view be a line making an angle of 45° with the axes of projection. The lower face, right hand face, and rear face of the object would be in shade. This is indicated

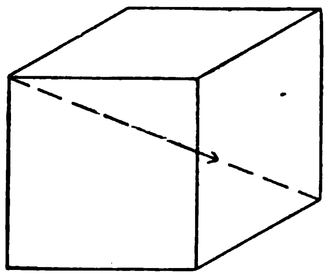


Figure 72.

on the pencil drawing by a letter S lightly penciled across each of the lower and right hand outlines of the object as seen in the front and side views.

In the top view, the right hand and rear lines would be shaded, but for the sake of uniformity with the other views, to avoid confusing the draftsman and the workman, and as the absolute truth in this matter is not essential, the right hand and the front (lower line on the drawing) lines are shaded as in the other views.

This method (although not exactly correct) is found to be quite satisfactory and is the conventional one in general use. The letters indicating the shade lines must be placed on the drawing without fail before it is brought to the inspector for criticism. They are to be made in pencil only and will be erased in cleaning the sheet just before placing it in the portfolio. When the drawing is inked the shade lines are made considerably heavier than the other outlines of the object. See plate of standard lines, Figure 53.

Shade lines may be determined upon the drawing by the use of the 45° triangle and the T-square in combination. Draw a few—three or four—short lines about 3/16 in. long and inclined at 45° from the left downwards, along each of the upper and left hand lines of each view, and just outside the view but not touching it. Let one of these lines be at the extreme upper right hand corner of the object and another at the extreme lower left corner, to represent the rays tangent to the object. Tangent means just touching the outside in such a way that the object would not be pierced if the tangent line were extended indefinitely. Place arrowheads at the lower ends of these lines near but not quite against the lines of the object.

The arrows thus made will indicate the direction of the rays of light. Lines of the object on the right hand and lower sides opposite these arrows will be shade lines, and these shade lines will begin

at points where rays of light are tangent to the object.

DIMENSION LINES.

The parts or details next to be placed upon the drawing are the dimension lines.

A dimension line is a line placed upon a drawing for the purpose of bearing a dimension number and of showing the limits of the distance stated by that dimension number.

A dimension line does not form any part of the outline of the object. No center line, or line of the object should be used as a dimension line. Figure 73 shows a rectangle with dimension lines and dimensions.

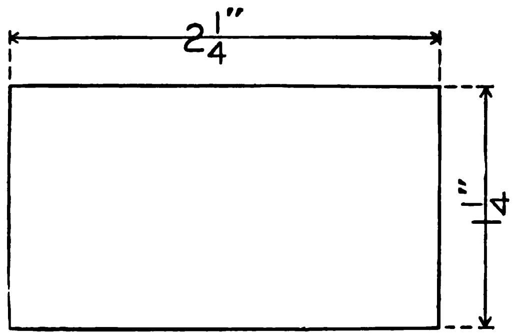


Figure 73.

It is not always easy to decide just what dimensions should be shown upon a drawing, but generally speaking there must be placed upon it dimension lines and figures to show all the sizes of the whole object and of each part of it about which a workman would need to know in producing the article shown.

Where two or more objects are shown put together, dimensions must be given fixing the positions of the objects in relation to each other, in addition to those necessary for the construction of each individual object.

A line appearing to be horizontal or vertical is assumed to be so unless otherwise marked. In all cases where a line is situated in some particular or specified position other than horizontal or vertical, such position must be indicated by a dimension arc properly placed and figured to indicate the required angle.

The dimensions of any mechanical drawing must duplicate those stated in the specification from which the drawing is made.

Placing dimension lines and dimensions requires good taste and judgment. Remember that the purpose of the drawing is to convey the greatest amount of information in the clearest way possible.

DIRECTIONS FOR PLACING DIMENSION LINES AND DIMENSIONS.

Each dimension should be placed where it was used in executing the drawing. This would seem the natural thing to do, yet most beginners not only fail to do it but frequently place dimensions where the distances stated were not laid off at all.

Use and place as many dimensions on the most important view as can be done to advantage and without making that view too intricate and obscure.

Do not repeat a dimension on the same or any other view, except in some very unusual circumstance where it will serve a useful purpose.

To place the dimension lines upon the drawing proceed as follows: First place the **extension lines.** These are very light dotted lines used to show the limits of the dimension lines. Make the dots 1/16 in. long placed 1/32 in. apart. See plate of standard lines, Figure 53, for illustration. Start the extension lines at the extremities of the object or line whose size is to be shown, and extend them out from it about 5/16 in. Between the extension lines and with its extremities touching them, draw the dimension line. Place the dimension line ¼ in. away from the object and make it a very light full line. See plate of standard lines, Figure 53, for illustration. Both extension and dimension lines should be drawn very lightly because they are to be finished in red ink which is a semi-transparent color. If the pencil work is made too black it will destroy the brilliancy of the red ink.

Dimension lines should, as a rule, be placed outside the outline of the object, but where that is impossible, or where it would take them too far from the lines whose dimensions are to be shown, they may be placed inside and so across the drawing.

In any case put the dimension lines on where they will appear to the best advantage, and will the least interfere with and obscure the drawing.

Place the dimension number across the dimension line and a short distance to one side of the center of the dimension line. By thus placing the dimension to one side of the center of the dimension line it will not come in contact with the center line of the object. Center lines of object are used in practical work and will be explained and used in later problems in projection.

Each dimension should also be placed so as not to touch or be very near any line of the drawing except the dimension line to which it belongs in order that either the dimension or the line in question may be erased or altered without injuring the other.

Make the integral figures of a dimension number 3/16 in. tall and the fraction figures each ⅛ in. tall. Allow a space of 1/16 in. between the numerator and the denominator. A fraction will thus cover vertically a space of 5/16 in. See plate of standard letters and figures, Figure 41.

Never use an oblique line between the numerator and denominator of a fraction, for when carelessly made it sometimes leads to error. Thus 1 3/16 in. might be mistaken for 13/16 in. Where the dimension ocurs upon a dimension line omit the fraction line entirely and let the dimension line serve for the line of the fraction.

Make each dimension read only from one or the

other of two directions, namely, from the bottom of the sheet or from the right hand side.

Arrowheads. An arrowhead is made up of two lines each about 1/16 in. long, placed at the end of the dimension line, inclined to form an angle of about 60°, meeting at the point where the dimension line terminates against the extension line, and just touching the extension or other lines between which the distance is given.

The arrowhead is to be made freehand and not by means of the triangle. Place an arrowhead at each end of the dimension line.

If a dimension is given on each side of the extension line, thus producing a double arrowhead with the points meeting, form the arrowhead not by four lines meeting, but by two lines twice as long, crossing each other.

LETTERING A PROJECTION DRAWING.

Every sheet of drawing should have upon it some lettering to better and more fully explain the purpose of the drawing. This lettering may appear in any or all of these general forms as follows:—

1st. **Individual Letters,** designed to draw attention to some particular points of the object.

2nd. **Explanatory Notes,** designed to convey information which may more readily and satisfactorily be given by the aid of words than by the drawing alone. Any individual feature or peculiarity of a certain part, or the manner of making it, or finishing it, may be explained by means of a note.

3rd. **The Title,** designed to state briefly what the object represented is. In theoretical work the title also specifies how the object is to be placed for representation. In elementary drawing, if more than one problem is placed upon a sheet, each problem must have its own appropriate title.

All lettering on mechanical drawings should be executed in neat, clear styles, and in such sizes and forms as may have been decided upon as satisfactory for the work in hand. See plate of standard alphabets, Figure 41.

Always draw height lines for any row of letters so that each letter in that row shall have its proper height and that an appearance of regularity and uniformity shall be given to the drawing.

Where several sets of these lines for letters come at any one part of the drawing, place them distant from each other a space equal to the height of the small letters in such lines.

All lettering must be penciled before being inked. This includes the titles of the first few problems. When the pupil has become skillful enough through practice to do lettering very well, he may ink in the title without having previously penciled it.

Remember to place the letters of a word near together, but allow between any two words the space of at least one and one-half average-sized letters—

for instance, one and one-half times the width of the letter N.

Following are more specific directions for executing the lettering on Problem 25.

Individual letters naming certain points on the drawing have been previously explained as follows: Those naming the planes of projection and the corners of the planes of projection, on page 104. Those naming the corners of the object and of the views of the object, on pages 104 and 105.

EXPLANATORY NOTES.

The next details to be placed upon the drawing are the explanatory notes. They are to be made in capitals and small letters of the prescribed freehand style, but of two-thirds the size of the letters used in the problem titles. The capitals are to be ⅛ in. tall and the small letters two-thirds as high. Do not attempt to get the latter measurement from the scale, but space by the eye only. The following names, Top View or Plan; Front View or Front Elevation; Side View or Side Elevation; are to be placed on the views to which they respectively belong. Both names for each view are to be put on. The names, Horizontal Axis of Projection, Vertical Axis of Projection, are to be placed along the lines to which they belong and ⅛ in. away from the lines.

The names just given are considered as explanatory notes.

TITLE OF A PROJECTION DRAWING.

The specifications for the problem form the title of the drawing in projection work, and are to be placed in the upper right hand corner of the sheet as shown in Figure 74, that being the only available space for them. Draw horizontal lines for the lettering. Place them away from the border and covering a space as indicated.

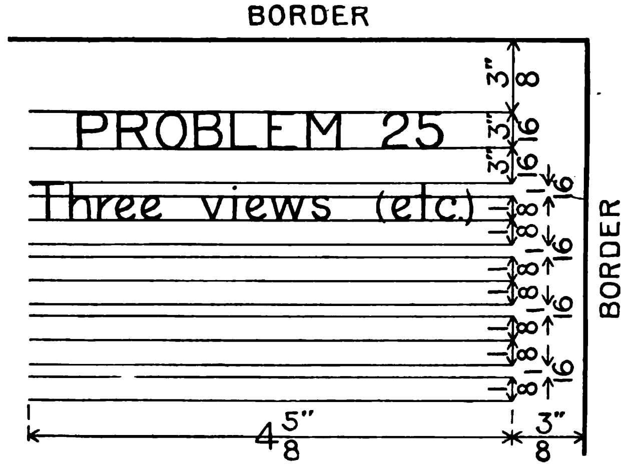


Figure 74.

Those parts of the curved projection lines from top view to side view which encroach on the title space should be erased.

Draw direction lines for the lettering and make the letters in the regular freehand style. Make the

heading PROBLEM 25, all capitals, 3/16 in. tall, and place it so as to be vertically above the center of the space to be occupied by the title.

Begin the first word of the body of the title against the line which indicates the limit of the left side of the title, see Figure 74. Review the directions for freehand lettering, see page 57, and carefully make the title to agree with them.

REVIEW OF THE CONSTRUCTION OF PROBLEM 25.

Review the construction of Problem 25 in the order given by the following analysis, and see that every detail is complete and in all ways executed according to the requirements.

Make a copy of this list of items in the notebook. Check off each item of the copied list as fast as it is found that that part is perfect.

1st. Place the draftsman's name and the date of beginning the drawing, see page 56.

2nd. Pencil the border, see page 56.

3rd. Draw the planes of projection, see page 103.

4th. Letter the planes of projection, see page 104.

5th. Letter the axes of projection, see page 104. Use height lines for these letters.

6th. Draw the views of the object, see page 104.

7th. Letter the views of the object, see page 105. Use height lines for these letters.

8th. Indicate the shade lines, and place the arrows representing rays of light, see page 106.

9th. Place the extension lines and the dimension lines, see page 108.

10th. Place the arrowheads and the dimensions, see page 109.

11th. Put on all explanatory notes, and any lettering not above specified, see pages 110 and 111.

12th. Put on the title, see pages 110 and 111.

After the drawing has been carefully completed in pencil it is to be submitted to the inspector for his criticism. When approved and signed by him it is to be inked.

INKING A PROJECTION DRAWING.

Review the directions previously given for inking a drawing, see page 77. For inking Projection Problems—Nos. 25 and following—two colors of ink are to be employed.

When inking a drawing begin with the parts in front and work back, thus avoiding the danger of making full, those lines which should be broken. This direction is especially valuable when the drawing is a complicated one.

Ink curves first. Then ink the horizontal lines, beginning at the top of the sheet and working down. Then pass to the vertical lines on which work from the left to the right of the sheet.

Make the projection lines very light; the lines of the object medium; the shade lines and axes of projection heavy; and the border, still heavier. See illustration of standard lines, Figure 53.

A sheet of projection work should be inked in the following order:

1st. Projection lines, black.
2nd. Lines of object, black.
3rd. Shade lines, black.
4th. Axes of projection, black.
5th. Center and base lines, together called main lines, red. (Main lines are not used in Problem 25, but will be explained in later problems.)
6th. Extension lines, red.
7th. Dimension lines, red.
8th. Dimension figures and arrowheads made freehand with a writing pen, black.
9th. Explanatory letters **H**, and **V**, and **SV**, made with the ruling pen, black.
10th. Other explanatory letters and notes made freehand with writing pen, black.
11th. Title, black.
12th. Border, black.
13th. Draftsman's name and other required data, black.

Clean the drawing and submit it to the inspector, who will affix his signature as soon as the work is satisfactory. When the drawing has been finally approved file it in the portfolio.

DEDUCTIONS FROM PROBLEM 25.

According to the conditions of Problem 25 the three sets of faces of the prism are parallel respectively to the three planes of projection and in the drawing it is shown that under these conditions, the planes constituting the faces of the prism are pictured on the planes of projection in their full or true sizes. The following rule may therefore be drawn from Problem 25.

RULE 1. A plane parallel to the plane upon which it is projected, is there projected in its true shape and dimensions.

It is evident from a study of Problem 25, and on consideration of the matter, that the sizes of the planes of projection are not absolute, but may be assumed at pleasure to correspond with and accommodate the dimensions of the object.

Inasmuch, however, as the lines separating the planes—that is, the axes of projection—are the only parts of the planes put to any use, only those parts need be drawn, and hereafter the remainder of the outlines will be omitted.

The general principles and methods of mechanical drawing now having been explained, it should be the aim of each pupil to regard any problem as consisting of two parts, as follows:—

1st. The **Analysis**; and, 2nd, the **Construction**, and to go about the solution of the problem in the order just given.

The Analysis is a statement of the conditions of the problem, and a consideration of the principles involved and the course of reasoning to be followed in solving the problem.

The Construction is the graphic execution of the problem.

It is not to be supposed that these two processes can be made quite as independent of each other as might seem to be indicated by the above statement, but it is evident that every student should carefully consider and plan what he is to do before he goes about it.

PROBLEM 26.

Three views of a horizontal rectangular plane 1⅜″ x 2″; the plane to be the top surface of the solid shown in Problem 25 and similarly situated.

Illustrate the problem by a piece of thin cardboard of correct dimensions, placed beneath the projection glasses in the position specified in the statement of the problem. The plane may be raised from the table by four pins thrust through the four corners of the cardboard so as to make its appearance more clear and evident.

In the notebook make three sketches showing the appearances of the plane when viewed from the three general positions for the observer. Refer to Problem 25 if necessary. Write the name of the view below each sketch.

Submit the sketches to the inspector for his signature and date and when the latter have been affixed, go on with the mechanical drawing.

Analysis:—Since the plane is a horizontal one it will be projected upon **H** in its true shape and dimensions, see Rule 1. And as it is to be considered as the top surface of the solid shown in Problem 25 and similarly situated, its top view will be like the top view of the upper surface of the solid shown in that problem, that is, a rectangle 1⅜ in. by 2 in. with its longer sides parallel to **V.** As the plane is parallel to **H,** it will be perpendicular to **V** and to **SV,** because those planes are perpendicular to **H.**

Therefore upon **V** and **SV** will appear such dimensions of the plane—if there are any—as are perpendicular to those already given.

A plane, however, has only two dimensions, and as the two dimensions of this plane, both show upon **H,** there can be no new dimension showing upon either **V** or **SV.** Upon **V** then, will appear an edge view of the plane showing the length of that dimension of the plane (2 in.), which is parallel to **V.** Its representation must be a line because that expresses length or extension without thickness.

A similar effect is shown upon **SV** where the plane will be represented by a line 1⅜ in. long because that is the dimension of the edges of the plane which are parallel to **SV.**

Construction:—Lay off the usual border and divide the sheet into two equal parts by a vertical line as Problem 26 and Problem 27 are both to be drawn on this sheet. Next lay off the axes of projection as shown in Figure 75, omitting the other outlines of the planes of projection because they are unnecessary.

Letter the axes as usual, see Figure 70, but omit their names on this and following problems. Centrally upon **H** draw the top view of the plane. Letter the corners of the top view to correspond with Problem 25. Do not forget to use the proper subscripts on the letters.

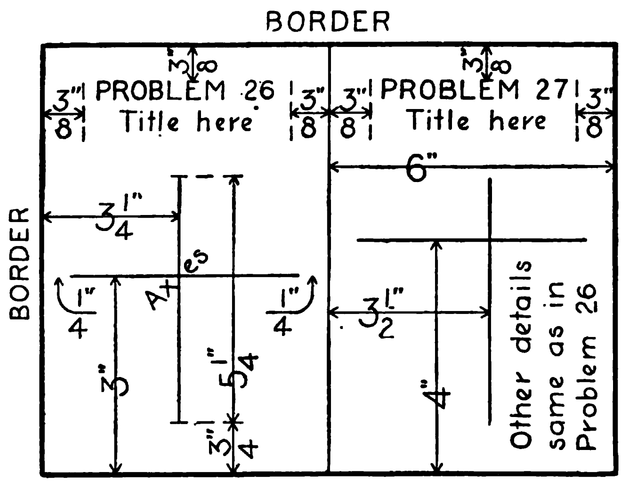


Figure 75.

Next drop projection lines from the top view across **V**. Draw the front view and letter it. Extend a projection line from the front view across **SV**. Complete the representation of the plane by drawing the side view, the dimensions and position of which should be fixed by projecting around from the top view. See page 106. Letter the side view. Problem 26 and Problem 27 must not be shadelined as it is not customary to shadeline planes. A shadelined drawing indicates that the figure shown represents a solid. Place the dimensions. Put the name of the top view on that view; the names of the front and side views below those views respectively; and put the names (abbreviated) of the planes of projection on the spaces representing those planes.

When any view is a line, as is the case in this problem, or is of such shape that the name of the view cannot well be placed upon it, the name may be placed a little below, above, or at one side of the view as may seem best under the circumstances. In either case it should be so placed as not to interfere with any other feature of the drawing if that can well be done.

Take care that the letters of these names are of the proper sizes. See page 111.

Place the title as shown in Figure 75, opposite. Complete both Problem 26 and Problem 27 in pencil before submitting the sheet to the inspector for criticism. After correction, approval, and signing, the problems are to be inked. The sheet is then to be submitted to the inspector for a third signature, which, having been affixed, the drawing is to be cleaned, removed from the board, and put in the portfolio.

DEDUCTIONS FROM PROBLEM 26.

According to the specifications, the plane represented in Problem 26 is a horizontal one. By analysis it was determined that the plane was therefore perpendicular to **V** and **SV**. And by the drawing it is seen that the representations on those planes consist only of a straight line on each plane. Therefore from these three facts the following rule may be deduced:

RULE 2. A plane perpendicular to the plane on which it is projected, is there projected as a straight line.

PROBLEM 27.

Three views of a vertical regular hexagonal plane of 2¼″ long diameter, this diameter to be parallel to H.

The long diameter of a hexagon is a line passing through the center of the hexagon and having its extremities in two opposite vertices.

The short diameter of a hexagon is the shortest line that can be drawn between two opposite sides, and passing through the center of the inscribed circle. It is equal to the perpendicular distance between the sides.

On a piece of stiff paper draw a regular hexagon of the required size. Cut out the figure and use it beneath the glass planes to illustrate the problem.

Analysis:—Since the plane is to be parallel to **V** it will be projected upon **V** in its true shape and dimensions, according to Rule 1. As it is parallel to **V** it is perpendicular to **H** and **SV** and will be projected on each of those planes as a straight line (see Rule 2). Problem 27 is, therefore, similar to the preceding problem, differing only in the requirement that the given plane shall be shown as parallel to a different projection plane. The problem is designed as a further drill on the principles illustrated in Problem 26.

Construction:—Draw and letter the axes of projection as usual. Centrally on **V** draw a regular hexagon of the required dimensions and placed as specified in the statement of the problem. Call the left vertex of the hexagon F and name the remaining vertices in alphabetical order passing around the figure in the direction in which the hands of a clock move—right hand rotation. Letter the front view to correspond with these directions. Use appropriate subscripts to the letters on each of the views.

Extend projection lines to **H** and **SV** and draw the views on those planes. As a matter of practice and to show that it can be done, draw the side view before drawing the top view. Place the side view centrally upon the space assigned to it, and project up and around to the top view, reversing the method of procedure hitherto used.

Each of the six vertices of the hexagon must be projected to, and show in, the side view and also the top view.

Observe that any two views of a solid, plane, line or point, fix the position of the object, whatever it is, and determine the position of the third view. Remember that planes are not shaded.

Place the dimensions. Read the directions on Dimensions and Dimension Lines, page 108. A dimension should always be placed as nearly as possible where it was used in constructing the drawing, and yet the dimension should not conflict with other parts of the drawing if such interference can be avoided. To avoid interference between the dimension line and letters on Problem 27, extension lines may be dropped from the right and left vertices of the hexagon and the dimension line placed below the figure and distant from it one-fourth inch.

Place the names of the planes of projection, and the names of the views which the planes bear. Place the title to correspond with that on the previous problem. Both Problems 26 and 27 are to be completed in pencil before the drawing is submitted to the inspector, as was directed in the text on Problem 26.

Follow all the directions concerning examination by the inspector as there given.

When the sheet is inked, the central division line separating Problem 26 from Problem 27 should be made of the same width as the axes of projection.

FURTHER DEDUCTIONS FROM PROBLEMS 25, 26 AND 27.

On each of the problems named select a line parallel to any one of the planes of projection, and study its representation upon each of the projection planes. It will be seen that in every case the representation of a line on any plane to which it is parallel, is also a line which is equal and parallel to the original line. From this fact the following rule is formulated:

RULE 3. A line parallel to the plane on which it is projected is there projected as a line equal and parallel to the line itself.

Compare this with the representation of a plane upon a plane of projection to which it is parallel.

Now study the representation of any line on any plane to which it is perpendicular. Observation will show that under such circumstances the line is represented as a point. Hence the following rule is deduced:

RULE 4. A line perpendicular to the plane on which it is projected is there projected as a point.

PROBLEM 28.

Three views of a line $1\frac{3}{4}''$ long, parallel to H and to SV.

Illustrate the problem by a pencil or some similar object placed beneath the glass projection planes.

Call the line F G. Read paragraph 6, page 105. Let F be the front end of the line. Study the views of this line F G.

Analysis:—Since the line is parallel to **H**, its representation on **H** will be a line equal and parallel to the line itself (Rule 3). The same is true of its projection on **SV**. Since the line is parallel to both H and SV, it is perpendicular to **V** and its projection there must be a point. (Rule 4.)

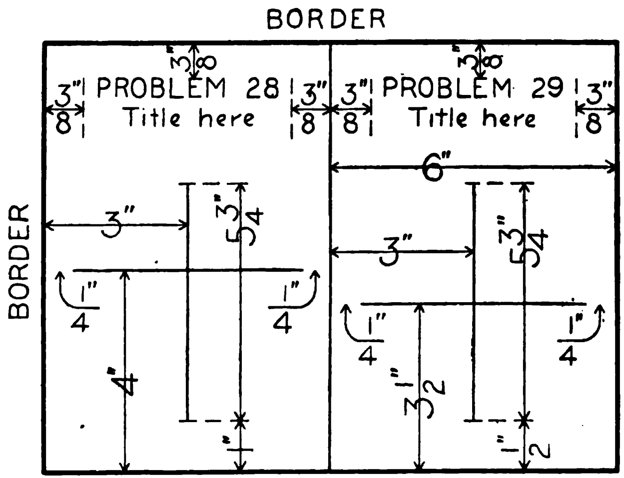


Figure 76.

Construction:—Prepare the paper as previously directed and as further shown in the accompanying diagram, Figure 76, and letter the axes as in preceding problems. Centrally on **H** draw a line 1¾ in. long, placing it as required in the specification of the problem. Letter it. Remember that at least two letters are necessary to name a line.

From the top view draw projection lines around to and across **SV**. Midway in the height of **SV** draw the side view of the line and letter it. From these views project the front view. Read the first paragraph on page 117.

It will be seen that but one projection line is used between the top and front views. Also that but one projection line is used between the side and front views. The intersection of these two projection lines determines the front view, which is therefore a point. Place the dimension of the line. Omit the names of the planes and the names of the views, on this and all succeeding problems, as those names should by this time be thoroughly understood.

DEDUCTIONS FROM PROBLEM 28.

By a study of the glasses used to represent the planes of projection and by comparison with any of the problems in Projections it will be seen that in the drawing, the line E B represents **H**, the top plane of projection as it appears when viewed from the side, that is, it is the side view of **H**. In a similar way E C is the top view of **SV**.

In studying Problem 28 it will be noticed that F_SG_S the side view of a line which is parallel to **H**, is parallel to E B which is the side view of **H**.

Again, $F_T G_T$, the top view of the given line (which is parallel also to **SV**), is parallel to E C the top view of **SV**. From these facts the following rule is formulated:

RULE 5. A line is represented as parallel to either of the planes of projection by making its projection parallel to the axis representing the given plane in the same view.

Observe that this representation of the line must be upon a plane of projection other than the one given. It is impossible to tell the exact relative positions of a line and a plane by the projection of the line on that plane. This will be made evident by placing some object, as, for instance, a pencil or a straight piece of wire beneath the planes to represent a line.

Imagine the space between the line and one of the planes of projection to be occupied by a plane, or insert a piece of paper to fill the space and illustrate the plane. This plane will be perpendicular to the plane of projection and will show on the plane of projection as a line (Rule 2.) The size of the angle included between the line and the plane of projection will not show at all. If the line and the plane happen to be, or are made to be, parallel to one of the other planes of projection, the plane, in all its dimensions—including, of course, the angle between the given line and the plane of projection to which it was originally referred—will appear in full size on this other or second plane. (Rule 1.)

Again, let the pencil or wire representing a line be revolved in any one plane and made to assume positions at different angles with a plane of projection. By looking through this plane of projection during the revolution of the line it will be seen that at no time is the angle between the line and the plane sufficiently apparent to be exactly determined. From a study of the problems already executed, and a course of reasoning similar to that just explained, another rule may be deduced and proven, as follows:

RULE 6. A line is represented as perpendicular or oblique to either of the planes of projection by making its projection perpendicular or oblique to the axis representing the given plane in the same view.

PROBLEM 29.

Three views of a plane and a point; the plane to be 2″ square and horizontal, with its front edge parallel to V; the point to be vertically 2¼″ above the center point of the plane.

The problem may be illustrated by a piece of paper and a short shawl pin having a large, round head. The paper should be cut to the required size and shape. The head of the pin is to represent the given point.

Analysis:—This problem consists of two parts; 1st, the projections of a given plane; and, 2nd, the projections of a point placed in a position having

given relations to the plane. The first part is practically a repetition of Problem 26, and the second part demands only a construction which has appeared repeatedly in each of the preceding problems, whenever the corner of an object or end of a line, or in fact any point, was located.

Construction:—Lay off the axes as shown by the diagram given in the preceding problem and letter them as usual. Centrally on **H** represent a plane as specified. Call the front left hand corner of the plane F. Letter the top view in alphabetical succession and in right hand rotation. Next draw the front view.

Do not fail to bear in mind that the problem calls for a point placed $2\frac{1}{4}$ in. above the plane, so that a vertical space of $2\frac{1}{4}$ in. will be required and must be allowed. Therefore the front view of the given plane cannot be placed centrally upon **V**, but the plane and the point must be grouped together, considered as one, and placed accordingly. Notice that the given point is located with reference to the center point of the plane, so that the latter must be located before the position of the former can be fixed. The fact that the middle point of the plane was used before locating the given point, and in order to locate the latter should be made evident by lettering both these points in their proper order.

The center point may be located by diagonals or by dimension lines, but be sure to use one of these means.

When inking the problem the diagonals should be made light red lines as they are construction lines and not lines of the object. Be particular to locate the central point of the plane by projection line and by letter. Put on the dimensions. Place the title as shown in Figure 76.

DEDUCTIONS FROM PROBLEM 29.

The chief value of this problem consists in the drill which it gives in locating a particular point as specified. The ability to locate any desired point is essential to the construction of intricate problems.

If two points can be pictured, a straight line, that is the line joining those points can be pictured. The projections of two lines will determine the position of the plane containing those lines. The projections of three points will determine the position of the circumference containing them, and of a plane containing the circumference. The delineation of any irregular line or curve can be accomplished by fixing a sufficient number of points and joining those points.

PROBLEM 30.

Drawing of a right rectangular prism $1\frac{1}{2}''$ x $2\frac{1}{4}''$ x $4\frac{1}{2}''$ having its largest faces parallel to V, and its longest edges inclined up to the left at 30° from vertical.

Illustrate the problem by placing the object beneath the glass planes as specified. In Problem 30

and succeeding problems it is to be understood that three views are required unless directions to the contrary are given.

Make a freehand sketch and submit it to the inspector. When the sketch has been approved the pupil may proceed with his mechanical drawing.

Analysis:—Since the largest faces are parallel to **V** they will appear upon **V** in their true shapes and dimensions (Rule 1.) Also, since they are parallel to **V**, they must be perpendicular to **H**, and will therefore appear upon **H** as straight lines (Rule 2), parallel to the horizontal axes of projection (Rule 5.) Now by inspection of the object beneath the glasses, it will be seen that the smaller faces of the object are inclined to **H** at angles greater than 0° (parallel), and less than 90° (perpendicular), therefore they will show on **H** as something between their true sizes (Rule 1), and straight lines (Rule 2); that is, they will show as plane surfaces having dimensions less than those of the corresponding faces of the object but greater in width than a line.

The apparent decrease in size of a line when represented upon a plane to which it is inclined, is called **foreshortening**. The amount of foreshortening depends upon the degree of inclination of the object to the planes upon which it is projected. It will be seen by further study, that the faces of the prism are foreshortened in both the top and side views but that it is impossible to determine the exact apparent length of the foreshortened surfaces. It would, then, be impossible to begin the drawing with either the top or the side view. Since, however, the front face is parallel to **V** and its representation there is in true size and form, the drawing may and should be begun with the front view.

Construction:—Lay off the paper according to the diagram given, see Figure 77, which shows the axes of projection.

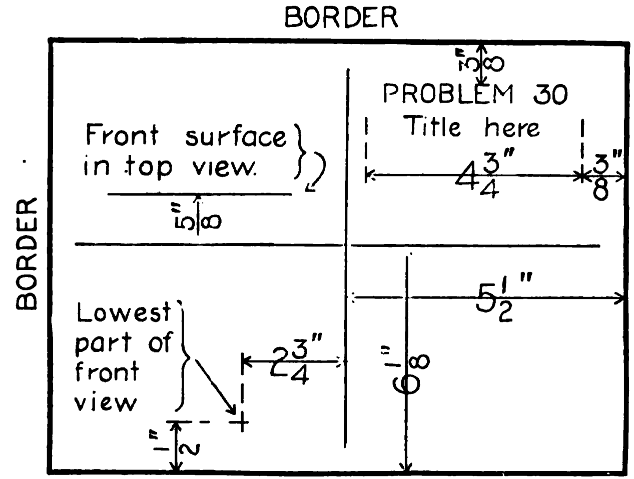


Figure 77.

Omit the letters of the axes on this and all following problems unless directed to the contrary.

Draw a rectangle of the required size and placed as specified, to be the front view. Call the left front

corner of the prism F and the upper front corner G. Designate the remaining corners in alphabetical succession and in right hand rotation. In naming the corners of the rear face, begin with the corner directly behind that corner of the front face which was first named.

Letter the front view to correspond with the letters just assumed. Make the letters vertical and not parallel to the inclined lines of the object. They should be made between horizontal lines as were the letters on previous drawings.

Project the front face to **H** where it will appear as a line (Rule 2.) Letter it.

From this line lay off lines to represent the thickness of the prism. The edges which these lines represent being perpendicular to the largest faces of the prism, are parallel to **H**, and will be pictured in full size (Rule 3).

Examine the front and rear surfaces of the prism. Determine whether they are continuous from the lower right hand corner to the upper left hand corner.

Represent them accordingly in each view. Pay especial attention to this suggestion as it is intended to correct an error which many pupils make in the top view. Complete the side view by projecting in the usual manner and letter it. $J_T N_T$ and $F_S K_S$ represent edges which could not actually be seen in top view and side view respectively, as they would in each case be on the far side of the object and therefore hidden by the part of the object intervening. This fact is indicated on the drawing by making the lines named, dash lines. The dashes should be three times as long as the dots of the projection lines. Study the plate of standard lines, Figure 41. Be very careful to make the projection lines and the hidden edges as described, so that they may be easily distinguished from each other.

Next indicate the shade lines by a letter S lightly drawn in pencil across the lines which it is designed shall be shaded. It might be supposed that inasmuch as the surfaces G L M H and H M N J are on the dark side of the object, the line H M separating them would be, as seen in side view ($H_S M_S$), a shade line. Such, however, is not the case, and the explanation is given by the following conventional rule which is adopted in practical work.

RULE 7. A line separating two adjacent surfaces, both of which can be seen, is never a shade line.

Place the required dimensions. The largest dimension of the front face should be made to read from the bottom of the sheet as on account of the position of the dimension line, the dimension can be more easily read from the bottom than from the right hand side.

Bear in mind that an angle signifies difference of direction, and the amount of such difference must be given by a dimension. An angle is measured and its size indicated by an arc included between its

sides and struck from its vertex as a center. See Problems 6 and 9.

If the sides do not intersect to form the vertex, prolong them until they do intersect and use their point of intersection as a center from which to strike the measuring arc.

DEDUCTIONS FROM PROBLEM 30.

As already explained it will be seen by a study of the model placed as specified, that some of its faces are oblique to two of the planes of projection and by a study of the drawing just completed it is seen that the faces in question are represented upon these planes to which they are oblique, in foreshortened dimensions. Hence the following rule is derived:

RULE 8. A line or plane oblique to the plane on which it is projected is foreshortened in projection.

Also it is seen that the drawing could not have been started with either the top or the side view, because it would have been impossible to determine the foreshortened dimensions of the faces of the prism. Therefore the following rule is adopted:

RULE 9. Begin the drawing of any object with that view which best represents it, and in which the largest number of its parts show in their true shapes and dimensions.

Refer to Problems 27 and 29 and compare the rule just given with the method adopted in starting those problems.

PROBLEM 31.

Drawing of a solid Greek cross, having arms 1″ square by 4″ over all, one pair being vertical and the other pair inclined 30° to SV, the back arm being nearest SV.

Place the model beneath the projection planes as specified, make a freehand sketch and submit it to the inspector. Notice that the object is specified as solid therefore there will be no joints where the arms meet.

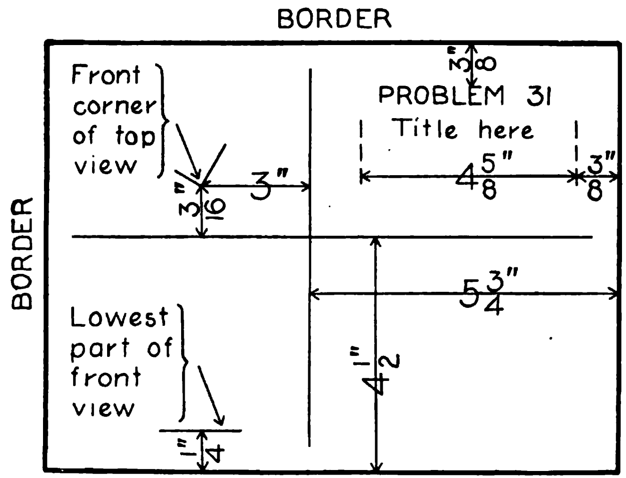


Figure 78.

Analysis and Construction.—It is found by a study of the model placed according to the specifications,

that all the surfaces of the cross are inclined to **V** and **SV** and do not therefore appear upon either of those planes in their true dimensions, but are foreshortened in projection (Rule 8). The true length and width of the horizontal arms and the true size and shape of the ends of the vertical arms appear on **H** (Rule 1) and it is there that the drawing must be commenced (Rule 9).

In making this and similar drawings, special care must be taken to distinguish between the projection lines and the hidden lines of the object. Refer to the plate showing standard lines, Figure 41, and notice the differences in form and width of the two kinds of lines in question.

There are 32 edges on this object and every one must be properly represented in each view. As before stated, the cross is supposed to be solid. Therefore there will be no joints and consequently no lines representing joints where the arms of the cross join. No lettering need be put upon this drawing except the title which is to be placed as shown in the diagram, Figure 78. Having completed the different views of the object, indicate the shade lines. Much care will have to be exercised in order to get the shade lines correct. Review Rule 7.

Next place two sets of dimension lines, each set including an "overall" dimension and a series of detail dimensions. **An overall dimension** is one from outside to outside of the object. **A detail dimension** gives the size of some small part. In measuring an object take each overall dimension in one measurement, if it can conveniently be done, thus avoiding possible error in obtaining it by adding together several measurements. See that the overall dimension is equal to the sum of the detail measurements which compose it, thereby checking and proving both sets of measurements. Take each measurement from a center line or finished surface, in order that it shall be accurate. Locate it on the drawing in such a way as to indicate the working edge or working face, thus showing the workman where he shall begin to lay out his work.

A Working Edge or Working Face is explained as follows:

It is evident that a dimension can not well and accurately be laid out from an irregular line or rough surface.

Having secured a piece of material in the rough state, which is to be finished to certain prescribed shapes and dimensions, the workman first trues up some line or surface of the object and from it proceeds to lay off the required dimensions.

This edge or surface first trued up and which is used as a base of operations from which to lay off other dimensions is called a **Working Edge** or **Working Face** as the case may be.

The final dimension in a string or series of detail dimensions is called (if inserted) a **Closing-in dimension.**

It is oftentimes advisable to omit the closing-in

dimension in order to indicate more clearly the working edge or face, and the order of construction.

When the final detail dimension of a series is omitted it is evident that the workman will have to begin his work from the other end of the object which face is in consequence called the working face.

Omit the closing-in dimensions on this problem.

Overall dimension lines should be placed outside of detail dimension lines. A detail dimension line should be placed 1/4 in. from the object and the overall dimension line 1/4 in. further, that is, 1/2 in. from the object. These distances may, of course, be modified somewhat, if the clearness and good appearance of the drawing are improved by so doing.

Dimension numbers exceeding one inch which include fractional parts of an inch should be written as mixed numbers, and never as improper fractions; thus 1 1/8 in., never 9/8 in. Dimensions greater than one foot and not exceeding two feet should be given in inches, thus, 21 in., not 1 ft. 9 in. This method allows for the convenient use of an ordinary two foot rule since its graduations are numbered consecutively up to 24 in. Dimensions greater than two feet should be given in feet and inches with the proper marks or abbreviations affixed, thus 3 ft. 4″, or 4 ft. 6 in.; or 5′—8″. The first method given is the preferable one. If the third method is used, care must be taken to insert the dash as shown or the dimension may be taken for 58″. Review all the directions previously given for placing dimensions, see Problem 25.

Do not fail to show the angle, because it is a dimension quite as much as though it were measured in inches.

Review the preceding problem. Owing to the position of the cross in relation to **SV** the lines including the specified angle do not meet on the paper. They may be continued in pencil out on to the board and the point in which they meet used as the center from which to strike the arc. When finishing in ink the side of the object extended should be made a dotted red line nearly to the border showing that it is a construction line and not a line of the object. It is in fact, an extension line and should be so made.

That part of the line from a point inside, near the border, and extending outside may be omitted.

Pay especial attention to correctly locating the shade lines in this drawing. Review Rule 7.

PROBLEM 32.

Drawing of a right vertical pyramid of 4 1/4″ altitude, with a base 2 1/4″ square, and having the edges of its base inclined 45° to V.

A pyramid is a solid bounded by four or more planes, one of which is a polygon of three or more sides, and the remainder are triangles which meet in a common vertex. The polygon is termed **the base** of the pyramid, and the pyramid is called tri-

angular, square, pentagonal, etc., according to the shape of the base. The triangles are called **the lateral faces** of the pyramid.

The point in which the lateral faces meet is called **the vertex** or **apex** of the pyramid, and the line in which any two lateral faces meet is called **a lateral edge.** The line in which a lateral face and the base meet is called **a basal edge** or **edge of base.**

The axis of a pyramid is an imaginary line from the apex to the center of the base. **A right pyramid** is one whose axis is perpendicular to its base.

A slant or oblique pyramid is one whose axis is oblique to its base.

A regular pyramid is a right pyramid whose base is a regular polygon.

The altitude of a pyramid is the length of the perpendicular from the apex to the base, or to the base produced (extended).

The slant height of a pyramid is the length of the perpendicular from the apex to the middle of one of the edges of the base. The term "slant height" is applied only to regular pyramids.

Analysis and Construction.—Problem 32 gives the first example of a model having surfaces inclined to each other and showing therefore chiefly in foreshortened dimensions.

The pupil is to decide for himself with which view to commence the drawing.

There should be little question about it after having executed the two previous problems.

After having decided upon the view with which the drawing should be commenced, and before starting it, the pupil is to calculate the layout of the drawing.

By the **layout of a drawing** is meant the approximate determination of the sizes of the views and their placings on the sheet, so that the finished drawing shall be clear, the views each surrounded by margins or blank spaces sufficient to make them well separated and quite distinct and that the drawing as a whole shall give to the eye an agreeable impression because of its symmetry and balance.

This layout or planning of the views on the sheet is a part of the work which every good draftsman performs in starting the drawing of an object which is already constructed or of which the general dimensions are known with considerable definiteness. Planning the work in this manner gives good looking drawings, economizes paper, serves to show all work in the least space possible, ensures desirable grouping of objects or parts and is of great value in practical work.

In calculating the layout of the sheet for Problem 32, the pupil is to plan for the placing of the axes of projection as they are to be used in this problem.

Axes of projection are not used in practical or shop work, as will be explained later.

For this problem first calculate the layout from front to rear of the sheet, proceeding as follows:—

Conceive the object to be placed as specified and

by inspection and measurement determine the width of the top view from front to rear.

To do this the pupil will have to make a sketch of the base in true size, and from it scale the measurement desired. As this part of the work needs to be only approximately exact it will suffice to calculate only to the nearest 1/8 in.

Next determine the height of the front view. The sum of these distances just ascertained constitutes the amount of space to be occupied by the drawing between the upper and lower borders of the sheet, and by its subtraction from the total distance between the borders is found the amount of space to be left blank.

This blank space may be divided into three equal parts, giving clearance between the views and also between each border and the neighboring view, but it is better to make the central space a trifle—say 3/16 in.—wider than either of the outside spaces, as it is to be partially filled by the horizontal axis of projection passing through its center and equidistant from the two views. The spacing of the views from left to right of the sheet might be similarly planned on drawings where no axes of projection are used, as is the case in practical work and as will be the case on later drawings in this series. But for this problem the vertical axis may be placed with very little calculation because there is abundance of room, and the top and front views may be placed centrally—right and left of the sheet—upon their planes.

Then two views of the object having been placed, the position of the third—the side view—is fully determined as has been ascertained in previous problems.

Next make in the note book a sketch showing views similar to those that will be made in the mechanical drawing, but without projection lines. On the sketch show in figures the amount of room occupied by each view as used in calculating the placing of the axes according to the directions just previously given.

Also indicate on the sketch the positions of the axes in relation to the borders in a style to agree with the diagrams for Problems 30 and 31. It is not necessary to specify the amount of clearance between the ends of the axes and the borders.

Show the clearance distances between the views and the axes.

See that the sum of the clearance distances and the widths of spaces occupied by views either vertically or horizontally across the sheet, equals the distance between borders in that direction.

Submit the sketch to the inspector and when it has been approved proceed with the mechanical drawing.

Pay attention to the following rule:

RULE 10. A line parallel to the rays of light is never a shade line.

One dimension is not sufficient to show that a figure is a square.

Angles are dimensions and must be shown upon the drawing. Read Rule 6 at this point.

Indicate the size of the angle according to the directions given in Problem 30. Such extensions of the sides should be inked red to show that the lines are explanatory and not a part of the object.

PROBLEM 33.

Drawing of a right rectangular pyramid lying horizontally on one of its larger faces, and having its axis parallel to SV, with apex in front. Altitude of pyramid $4\frac{1}{4}''$. Base $2\frac{1}{2}'' \times 3\frac{1}{2}''$.

Place the object as specified and study its form and dimensions.

Analysis:—It will be seen that all the faces of the object are inclined to the planes of projection. In consequence the given dimensions show chiefly in foreshortened length.

Of the various views, the side view best represents the object because in that view two of the dimensions show in full size. It would seem then, that the drawing ought to be commenced with the side view (Rule 9). But further study shows that the side view cannot be drawn to at once show the object in the specified position, because although two lines of given dimensions show in full size their inclinations are not known, and there is no way of determining these inclinations. It is therefore impossible to start the drawing in the usual way, that is with one of the three ordinary views. Under these circumstances it becomes necessary to make use of an intermediate drawing and of a process called revolution.

It sometimes happens that an object or more frequently, some detail of an object, is so situated, as in the present instance, that the drawing of it cannot be made directly. Under such circumstances an auxiliary or primary position of the object must first be assumed and represented, and from this primary view the representation of the object in its true position be worked out. The method of drawing an introductory view and then moving or swinging such introductory or primary view so as to represent the object in the position specified and required is called **Revolution.** It is this process of revolution that it is desired to illustrate and explain by this problem. Representing the object in an auxiliary position necessarily means more drawing to be done, therefore the aim should be to assume the primary position as nearly as may be like the final or required position, and so to minimize the work.

Experiment will show that a drawing of the object could be made if the object were placed in a position similar to that specified, but having its apex elevated till the axis is horizontal, because in such position the given dimensions show in full size on one or another of the planes of projection, and all

lines necessary to complete the views can be readily located and determined for that position of the object. From this primary position the object may be revolved into the required position by swinging it about its lowest edge, and the revolution may be shown on paper by similarly swinging the proper view about the point representing the edge on which the object revolves. By placing the pyramid on a table in the position specified, then swinging it into some similar auxiliary position in which it can be drawn, and swinging it back and forth several times, the pupil can easily determine in which view the revolution best shows. It is with that view the drawing should be commenced.

Before the mechanical drawing is begun, the pupil is to make a sketch showing his idea of the primary position and also of the revolved position.

To better understand the revolution of a view he may cut a piece of paper to fit the view which is on the plane where the revolution shows most fully.

Hold the paper on the drawing by a pencil point placed upon that vertex of the triangle which is to act as the center about which the figure is to revolve. Swing the paper figure back and forth a few times. Sketch the paths of revolution of the two revolving vertices. Sketch the figure in revolved position.

Sketch the revolved position in the two other views already located. Submit the sketch to the inspector.

Construction:—Place the axes of projection as shown in the accompanying diagram, Figure 79. Draw each view of the primary position, making the lines very light dash lines and submit to the

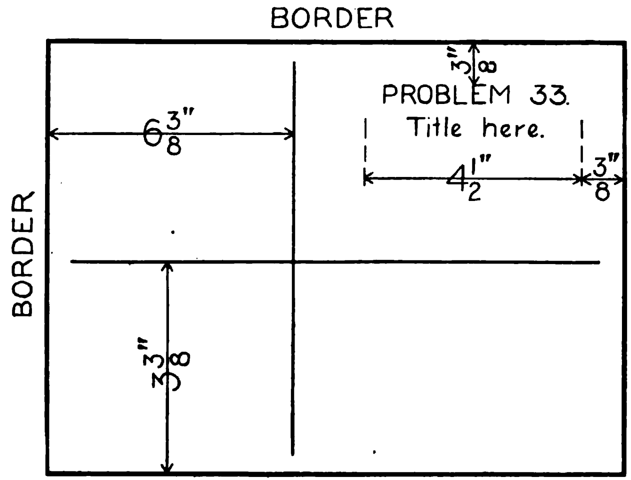


Figure 79.

inspector for approval or correction before going ahead with the revolution. This drawing is, therefore, to be signed four times.

Next proceed to revolve the object into the required position. This revolution is to be graphically made upon that plane on which the actual revolution of the object itself best shows. Swing the object several times from primary to required position.

Observe the path of motion of the apex and de-

cide whether each point of the object passes through a similar or entirely different kind of path. To draw the revolution set the compasses at that point of the drawing, as a center, representing in the view in which the path of revolution best shows, the edge about which the object revolves. Open the compasses to a radius reaching from the center just assumed to the apex of the pyramid.

Strike an arc representing the path of motion of the apex in revolution, and terminate the arc when the apex has reached the specified position.

Draw indefinite line or lines to represent the path of motion of the remainder of the figure. Observe the shape of the figure representing the entire object in this view. Reproduce this figure in revolved position according to the method adopted in Problem 10.

The arcs of revolution, it will be noticed, are parallel to the plane upon which appears the view with which the work has thus far been done.

Since the arcs are parallel to this plane, they are perpendicular to the other planes, and the circles of which they are parts will be represented on these other planes as straight lines passing through the original positions of the points.

Verify this statement by study of the object.

Complete the required (revolved) positions in the two other views.

Be particular to show in top view the two hidden edges of the face on which the pyramid lies. Be sure to put the dimensions on just where they were used in laying out the drawing. Make the arcs of revolution dotted lines and ink them red. The axis of the pyramid should be inked a full red line as it is an imaginary line.

PROBLEM 34.

Drawing of a cube with edges $1\frac{3}{4}''$ long having two of its diagonals parallel to SV, one of which diagonals shall also be horizontal.

A cube is a polyhedron bounded by six equal square faces. For the definition of a polyhedron, see Problem 25.

A diagonal of a cube is a line joining any two vertices of the cube not in the same face. See Figure 72, Problem 25.

Analysis:—Problem 34 is designed to give further drill on the principles explained in the preceding problem. As in Problem 33, so in this problem, the model should be placed as nearly as possible in the required position, to avoid unnecessary labor. Count the number of diagonals in the cube. Select any two of these, and hold the cube so that the diagonals chosen are situated as specified. Decide whether the cube could be at once drawn in the required position. State the rule which gives the reason for such decision. Swing the cube into some auxiliary position with a view of which it would be possible to commence the drawing. It will be found that the cube may be swung in two directions, either of

which will answer the desired purpose. Select that primary position for the object which will cause the drawing to best be commenced on the front plane of propection, with a view that shows one face of the cube only.

No sketch of this problem or succeeding problems is required unless directions to make such sketch are specifically given.

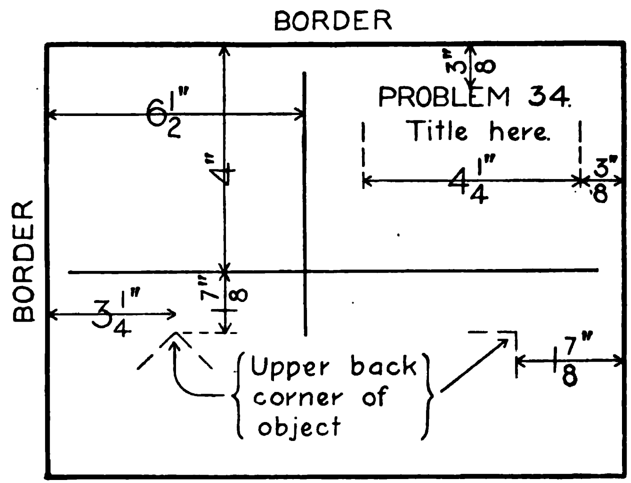


Figure 80.

Construction:—Place the front and **top views** of the cube in primary position as directed in the diagram, Figure 80.

Draw the three views of the primary position in light dash lines. Represent in a similar way the specified diagonals on that plane (only) where they show in full size. It is of the utmost importance for the ready comprehension of the problem that these diagonals shall be shown.

Choose the center of revolution about which to swing the cube. To decide upon what point to use as this center, remember that, having assumed two diagonals parallel to **SV**, it now remains to make one of them also horizontal by the process of revolution.

In revolving a line into any required position, the process is simplified greatly if one end of the line is kept stationary and the other end revolved about it till the desired position is reached. Therefore in this case the center of revolution should be chosen at an end of one of the diagonals selected.

Swing the cube into the required position, using the upper back corner as the center of revolution. Stop the revolution when the diagonal through this corner becomes horizontal. Draw the view of the revolved object on that plane where the path of revolution best shows, and on which the whole process of revolution is most evident.

Project the different points of this revolved view to the other planes of projection and complete the views on those planes. Decide upon the shade lines **by use of the** triangle, as it is difficult in this problem to determine them by inspection. Put on the rays of light which are tangent to the object.

Review the definition of tangent, see Problem 14.

Review if necessary the text on shade lines in Problem 25.

After the drawing is approved, finish it in ink, making the object as shown in primary position in black dash lines, and the diagonals in primary position in red dash lines. The diagonals in required position are to be made red full lines.

Where a black line and a red line fall in the same place give preference to the black line as being the more important. Ink the tangent rays of light.

It will be noticed when the problem is completed that the outline of the front view is a regular hexagon.

If the work has been accurately done the compasses can be set at the center of this hexagon and a circumference drawn which will just touch each corner of the cube.

Now as the sides of a regular hexagon are equal to each other and to the radius of a circle circumscribed about the hexagon, it is evident that the edges of the cube as finally represented in front view are all equal. This view of a cube is called its **isometric projection** and it is, as will be seen, a sort of perspective representation.

It will be more fully explained later in the course.

PROBLEM 35.

An oblique triangular pyramid with equilateral horizontal base. Rear edge of base parallel to V. Length of edges of base 3″. Front lateral edge of pyramid parallel to V and inclined up to the right at 30° from vertical. Altitude of pyramid 3″. Required:—To show on V the rear face of the pyramid in its true shape and size.

Review the definitions of slant or oblique pyramid, and of altitude of a pyramid, see Problem 32.

Analysis:—In the two problems just preceding it has been explained how, when it is wished to show a solid in some peculiar position and one in which it is difficult to at once draw the required views, the problem may be much simplified by first drawing the given solid in some primary easily pictured position, and then revolving it into the position specified and required.

This process is not difficult or tedious with simple geometric solids, but if the object to be shown consists of many small parts, the operation at once becomes too complex and elaborate to be of practical value. Again, it is seldom that it is necessary to represent any structure in other than what may be termed a natural position, that is, one in which the main lines of the object are either horizontal or vertical. It frequently happens, however, that some detail of a structure when first drawn in position is oblique to the planes of projection, and does not therefore show in full size or in a way sufficiently clear to convey to the workman the desired information. Under such circumstances, the detail in question may be treated independently of the main

object, and by the method of revolution be brought into such a relation to the planes of projection that it will be projected in true shape and dimensions, thereby giving completely and accurately the information necessary to the workman.

The present problem gives practice in the revolution of a single detail of an object as just explained, this detail being the rear face. It is required, according to the specifications of the problem, to show on **V** the true size and shape of the rear face of the pyramid. It will be seen by inspection that the usual three views of the object placed as specified do not show this (Rule 8). In order that the face may show as desired it must be parallel to **V** (Rule 1), and since in original position the face is not parallel, it must be revolved sufficiently so that it shall be. To do this, let it be considered that the face may be detached from the pyramid, treated independently as a plane, revolved as desired till it is parallel to **V**, and that it is then there projected.

Construction:—First draw the usual three views of the object. Place them as shown in the accompanying diagram, Figure 81.

The projection usually selected by the pupil with which to commence the problem is the top view, but he at once finds a difficulty in completing it. In each of the preceding problems the view with which a pupil would naturally begin can be completed before passing to other views. In this problem, however, such is not the case. The drawing can be begun with either one of two views, but the pupil naturally and almost invariably begins with the top view. After the base is laid out, however, he is usually at a loss to determine the position of the apex.

This must be located by projecting the base to the front view, erecting the front lateral edge as

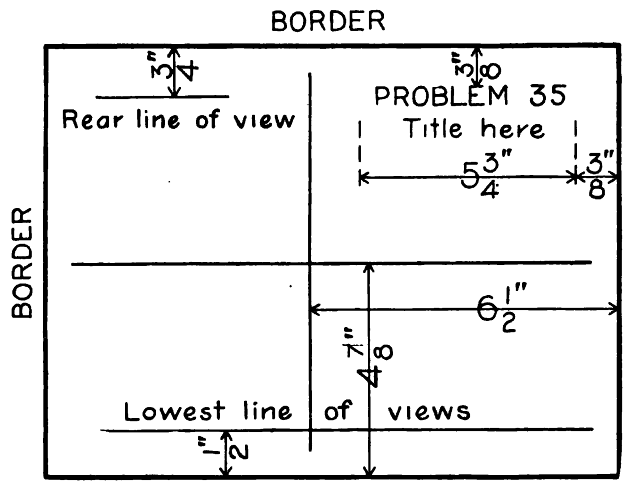


Figure 81.

specified and terminating it at the required height above the base.

It must be borne in mind that the altitude of a pyramid is the perpendicular distance from the apex to the base or to the base produced, that is, extended. Having completed the front view, the

apex may be projected to the top view and that view completed. The side view is then easily drawn.

This method of beginning a view, passing to another view, then passing back to the former, or perhaps to a third view, working at each alternately, and carrying them all on to completion together, is not only allowable, but is in many cases, absolutely necessary. On drawings of elaborate and complicated structures, a detail, that is, some particular feature of the object, may look all right as it appears in one view, but when placed in another view, it may be seen that it would be quite impossible to give the part such form or dimensions as were being planned for it. Under such circumstances the detail must be sketched in as best it may in the second view, modified in the first view, and so completed by working alternately on the different views. A skillful draftsman will always carry on two or more views at the same time unless the object is so exceedingly simple that all the facts about it may be shown by one view.

When the three main views have been completed, proceed with the second part of the problem—to show on **V** the rear face of the pyramid in its true shape and size.

It will be seen by inspection of the object and the drawing—see side view—that the rear face of the pyramid is perpendicular to **SV** and that its projection on **SV** is foreshortened into a line (Rule 2). On **SV** then, the required revolution may most easily be made and the line representing the face in question may be swung about any chosen center till it is vertical, when it will be parallel to **V** as required. Study and experience show that it is best to revolve the line about its lower end, for it must be remembered that the lower end is not really a point, but the projection of a line (the lower edge of the base) perpendicular to the plane of projection, and that by keeping this side in its original position and swinging the opposite corner—a point merely—less work is involved than would be required in doing just the contrary. On **SV** then, let the face be revolved about its lower edge or end, till it is parallel to **V**. The apex will describe an arc which is part of a circle parallel to **SV** and therefore perpendicular to **V**. This circle perpendicular to **V** will appear upon **V** as a line (Rule 2), and every point in it must be in this line. The line will be a vertical line because the circle is parallel to **SV** which is a vertical plane. The revolved position of the apex will therefore be found in front view on a vertical line passing through the original position of the apex, and at a height above the base of the pyramid determined by projection from the side-view. Since the lower edge of the face was used as the center of revolution, it will maintain its original position, and by connecting it on **V** with the revolved position of the apex, the position and therefore the size and shape of the given face are fully determined and shown as required.

Notice that the right hand edge of the rear face in revolved position must be a straight line.

The revolved position will not show in top view, as its projection coincides with the original position of the lower edge of the given face (Rule 2).

Complete the drawing by the indication of shade lines and the placing of dimensions as usual, and submit it complete in pencil to the inspector for criticism. Bear in mind that extension lines must be at right angles to any line whose dimension it is desired to show. If they are not so, the dimension line included between them is apt to be greater or less than the given line itself. When the drawing has been approved, it should be inked. The views of the back face in revolved position should be inked with full lines—except where hidden—of the width usually employed in outlining an object. The arc of revolution is to be made a dotted red line.

PROBLEM 36.

Vertical regular hexagonal pyramid with front and rear edges of base parallel to V. Altitude of pyramid 3½″. Edge of base 1½″. Required:—to place center and base lines; and to show the rear face of the pyramid in true size and shape by a fourth view made on an auxiliary plane.

Analysis:—In the preceding problem was shown one method by which the true size and shape of some detail of an object may be found. Similar results can be obtained by another process, which, being more widely applicable, is usually employed. This second method requires the introduction of a fourth plane of projection termed an auxiliary plane.

An Auxiliary Plane is so called because of the assistance it gives in the performance of the work of projection. The view made upon an auxiliary plane is called an **auxiliary view.**

In order that the detail may show in true dimensions upon the auxiliary plane, the plane must be passed—that is, drawn or constructed; passed is the technical term—parallel to the detail in question, which detail then being projected upon the plane, shows as desired, according to Rules 1 and 3.

The auxiliary plane bearing the required projection is then revolved until it is parallel to and coincident with one of the three original or main planes of projection. In this position the fourth projection of the given detail appears as do the usual projections in all previous problems, on the one picture plane made by the swinging out of the planes of projection to correspond with the surface of the paper, or other material on which the drawing is made. The revolution of the auxiliary plane is made by swinging it about its trace, that is, the line formed by the intersection of the auxiliary plane with one of the main planes of projection.

A Trace is the line formed by the intersection of two planes. Either plane may be said to make a trace upon the other.

In projections, however it is usually considered

that the auxiliary plane makes a trace upon one of the main planes of projection. The auxiliary plane may of course have some definite size, but it is customary to consider it of indefinite size as in the case of the main planes.

It is evident that the auxiliary plane may be perpendicular or oblique to the main planes; that it will have more than one trace if it intersects more than one of the main planes; and that it will have no trace on either of the main planes to which it is parallel, because the two do not intersect.

Illustrate these planes and verify these statements, using the glass planes to represent the main planes of projection as before, and using a piece of paper to illustrate the fourth or auxiliary plane.

In practical work little advantage arises from the use of planes oblique to all the main planes. Therefore an auxiliary plane is usually chosen perpendicular to one of the main planes, upon which it always and necessarily appears as a straight line (Rule 2).

Usually even the trace is omitted because, after the theory of this method is well understood, the trace is of no value. In the present problem definite dimensions are assigned for the main planes, and in consequence for the auxiliary plane also. In the next problem the trace only will be required, and in the succeeding problems even that will be omitted, except in the case of cutting planes whose use will be explained later.

In order that a trace may be readily distinguished from the other lines of the drawing it is made as a very light dash—dot—dash line. See plate of standard lines, Figure 53. Center Lines and Base Lines will be explained in the course of construction of the problem.

Construction:—Lay out the main planes of projection according to the accompanying diagram, Figure 82.

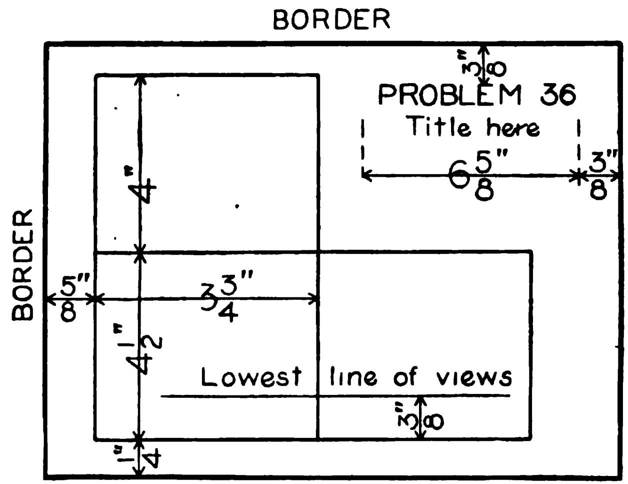


Figure 82.

The width of the side plane of projection is purposely omitted in order that the pupil shall determine it for himself. Consult Problem 25.

Submit the drawing showing the complete con-

struction of the planes of projection to the inspector for approval and signature before proceeding with the drawing of the object. When completed and accepted this drawing will therefore bear four signatures by the inspector. Draw the usual three views of the object, placing the top view centrally upon **H**. As a matter of practice, construct the hexagon entirely with the T-square and the 30x60 triangle as follows:—

Fix the position of the center of the hexagon and through it draw a horizontal line with the T-square. Along this line lay off the long diameter of the hexagon, and at the extremities draw with the 30x60 triangle, inclined lines to form the sides of the hexagon. Determine the length of these sides by lines drawn through the center of the hexagon, with the same triangle. Connect the extremities of the sides by lines drawn with the T-square, thus completing the hexagon.

Place the base of the pyramid in front view 3/8 in. above the lower edge of **V**. Letter the points of the pyramid, placing F at the left hand vertex of the base, and follow the usual order in lettering which should bring M at the apex of the pyramid. Also place N at the point where the projection line from J_T crosses the vertical axis of projection; O, where the line M_TM_F crosses the horizontal axis; P, where the vertical projection line through M_S crosses the horizontal axis; and Q, where the projection line connecting the front and side views of the base of the pyramid crosses the vertical axis. Examine the drawing and observe that:—

1st. The lines F_FQ and QH_S form one continuous straight horizontal line which may be regarded as an edge view of the surface upon which the base of the pyramid is supposed to rest. This line is usually considered of indefinite length and is called a base line.

A base line is a line representing an edge view of the surface upon which an object rests. It is usually horizontal. Heights laid off above the base line in front view will be duplicated in side view and vice versa.

2nd. The lines M_TO and OM_F form one continuous straight vertical line M_TM_F. Let this line M_TM_F be produced (extended) in each direction, and terminated 1/4 in. outside of the view of the pyramid. Make it a very light full line as it is later to be inked a red full line.

Place the letter R at the upper extremity of this line and S at the lower. The line R S thus formed constitutes a center line for the top and front views, since the pyramid is symmetrical with regard to a plane passing through the vertex perpendicular to its base.

A center line is a line representing the edge view of a plane passing through the center of a figure or object.

An object is said to be **a symmetrical object** when it has for each point on one side of a plane passing

through it, a corresponding point similarly situated on the opposite side of the plane, in which case a line joining the two corresponding points is perpendicular to the plane and is bisected by it.

What appears upon the drawing as a line ROS should not be regarded as a line merely, but the edge views or traces upon **H** and **V**, of a plane perpendicular to **H** and **V**. Distances laid off to the right or left of this center line in front view will be duplicated in the top view, and vice versa.

3rd. The lines F_TN and PJ_S which are the traces on **H** and **SV** respectively of a center plane, through the apex and parallel to **V**, do not form a continuous line after the planes of projection are revolved out into the plane of the picture, but are situated at right angles to each other, and each one forms a center line for the view in which it lies.

4th. Since N and P were originally, that is, before the planes of projection were revolved out, one and the same point, they are equally distant from the point E, and may therefore be connected by an arc of 90° struck from the point E as a center and having the distance E N (E P) for a radius.

It is not usual to connect the center lines of the top and side views, but this point is mentioned to show their relation and correspondence, and they are to be so connected in this problem.

5th. Since the right-and-left center line of the top view corresponds with the vertical center line of the side view, it follows that distances laid off from this center line in one view are duplicated in the other view. By inspection of Problem 36 it will be seen that distances back of the right-and-left center line—usually called the horizontal center line—in top view, show in side view as distances to the right of the vertical center line; and distances in front of the right and left center line in top view, show in side view as distances to the left of the vertical center line. Inspect Figure 66, and it may help to better understand these statements.

The center and base lines are to be made in red, after the outlines of the object are completed in ink, and before the dimension lines and dimensions are inked.

They should be made to extend beyond the object ¼ in. In these problems introducing the use of center and base lines, and on which projection lines are used, the center and base lines are to be shown by placing red dots where necessary, between the black dots of the projection lines. In later problems the projection lines will be dispensed with and the center and base lines may then be drawn as they should be, that is, fine full red lines. Whenever a line of the object and a center or base line fall in the same place on the drawing, the black line (line of object) takes precedence over the red line (center line or base line) since it is the more important of the two. The black line, therefore, should be drawn and the red line omitted. In practical work projection lines and axes of projection are not used.

The positions of the views are fixed by assuming two of the main lines for one view, and one main line for another view, which fixes both the main lines in all views.

The main lines of an object are its center lines; or center line and base line if the object is symmetrical; or such lines as are naturally prominent if the object is not symmetrical.

Upon these main lines, which should be light full pencil lines when beginning the drawing, one view is then constructed, commencing with that view which gives the most complete and accurate information. From this view, and other data either given or assumed, the remaining views are then constructed. Dimensions may be transferred between the top and front views, and between the front and side views, in the usual manner, or by a new method, which is, laying them off from the main lines. This latter method must hereafter be employed between the top and side views, because the center formed by the intersection of the axes of projection will not exist, for the axes of projection will be dispensed with.

It will be seen by inspection of a drawing with center lines made upon the glass projection planes, that the center line of the side view is exactly as far distant from **V** as is the center line of the top view, and that the two center lines from one continuous line which may be regarded as the intersections with **H** and **SV**, of a plane parallel to **V**. Any point in either view may be referred to the plane and will be equally distant from it in each view, and as the point must first be laid off by the use of the scale in one view it may be similarly laid off by the scale in the other view. This is generally necessary in practice. It will readily be seen that the drawings of many objects, if made full size or to such a scale as to convey the desired information, would be of such proportions as to preclude the possibility of placing more than one view on a sheet of convenient dimensions. It is customary in consequence to draw main lines and to place reliance entirely upon the scale for correspondence of dimensions in different views of the same part.

Dimensions should be penciled in before submitting the drawing to the inspector, but as previously directed must not be inked till after the center and base lines are drawn in ink. One dimension to show the length of an edge of the base in top view will be sufficient. A figure which appears to be symmetrical is always assumed to be so unless otherwise marked.

See that each dimension is so placed as not to fall on any center line, base line, or other line of the drawing, except of course the dimension line on which it properly belongs.

The second part of this problem requires the draftsman to find by projection, the **true size of a plane**. This plane is to be the rear face of the pyramid, and its shape is to be shown in full and

true size upon a fourth plane of projection. The pupil should carefully review the analysis given just after the statement of the problem, and then proceed with the following construction.

It will be seen by the drawing that the rear face of the pyramid appears upon **SV** as a line, hence the face is perpendicular to **SV** (Rule 2). Now, since the auxiliary plane may best be shown upon that plane to which it is perpendicular, as explained in the analysis, it will here be shown upon **SV,** because to answer its purpose it must be parallel to the face whose size is to be found (Rule 1), and this face is itself perpendicular to **SV.**

The auxiliary plane should be represented by a dash-dot-dash line, extending from the horizontal axis of projection to the lower edge of **SV.** This is the conventional way of representing a trace and is illustrated on the plate of standard lines.

The trace may be placed at any desired distance from the object, depending upon the conditions of the problem, such as size of the object, space available upon the paper, etc.

In this instance let it be placed ⅜ in. from the object and terminating against the upper and lower edges of the side plane.

It may conveniently be drawn parallel to the face of the pyramid by the use of the triangles together as explained in Problems 1 and 7.

Place the letter T at the upper extremity of the trace, and the letter U at the lower extremity. Project $M_S H_S G_S$ upon the plane, or trace T U, by lines perpendicular to T U. These lines are made perpendicular to T U in accordance with the rule of orthographic projection which requires that all lines of projection from the object shall be perpendicular to the plane upon which the projection is made.

Let the point where the projection line from M_S intersects the trace be marked V, and the point where the projection line from $H_S G_S$ intersects the trace be marked W. V W then, is the projection of the rear face of the pyramid upon the fourth or auxiliary plane of projection. It does not of course give the true shape and size (except height) of the face, nor can these be shown till the auxiliary plane is revolved into the plane of the three main planes of projection. The auxiliary plane may be represented in this revolved position by completing a rectangle upon T U. Make the width of this rectangle equal to the width of **H,** the top plane of projection, in order to correspond with the definite dimensions assumed in this problem for the planes of projection. Represent the outline of the auxiliary plane by a full line except the left edge which, as it is a trace, is made a dash-dot-dash line as previously explained.

The construction of this auxiliary plane may be illustrated if necessary by using a glass or paper plane with the glass projection planes employed in the earlier problems. After the auxiliary plane has

been shown as revolved into the plane of the paper, lay out upon it a center line upon which to construct the full sized view of the rear face of the pyramid.

Letter the upper extremity of the center line X and the lower extremity Y. The position of X Y is determined by the fact that it must be as far distant from **SV** as the center line of the face itself —on the object—is distant from **SV**. Therefore place it as far from T U (which may be used to represent the side plane because it is that line of **SV** in which the auxiliary plane terminates against it) as M_TR, the top view of the center line of the face, is distant from EC, the top view of **SV**.

The direction of X Y must be parallel to T U because the center line of the face in question is parallel to **SV**—see top view, in which M_TR is parallel to E C as stated.

Also X Y is parallel to $M_SH_SG_S$, the edge view of the face, since both are parallel to T U. It is important to remember this point of the construction, as in advanced projection drawing and practical construction drawing, the trace is never made. Upon X Y lay off the true length of the center line of the rear face. This may be done by continuing the projection lines M_SV and H_SG_SW till they intersect X Y. Letter the former intersection M_A, the subscript $_A$ being used as an abbreviation for auxiliary, and call the latter intersection Z.

T U may be regarded as an axis of projection about which the auxiliary plane is revolved. The projection lines from $M_SH_SG_S$ cross the axis of projection T U, in straight lines perpendicular to the axis, in a manner similar to the projection lines between any two of the main views. M_AZ is the altitude of the triangle which is to represent the true size of the given face. The base of this triangle may be obtained in true size from the top view and its position is determined by the altitude M_AZ and the base H_AG_A. $M_AH_AG_A$ is the required true representation of the rear face of the pyramid.

As it is considered to be a plane merely, it will not be shadelined. It is obvious that the entire object might be projected onto the auxiliary plane, in which case being a solid, it would be shadelined to correspond with the other views.

This method of using a fourth plane of projection is frequently employed to better show some detail of an object in direct connection with some foreshortened or otherwise obscure view of the part.

Now that center lines and base lines have been added to the kinds of lines in use before, the order of inking a drawing will be as given in Problem 25, where it is directed that the center and base lines shall be inked directly after the shade lines are inked.

When objects are laid out on main lines, as will hereafter be done, these main lines will be penciled

at the beginning of the drawing, consequently much earlier than they were in this problem, but the order of finishing in ink will be the same as just stated.

Consult the plate of standard lines frequently to see that the different kinds of lines are made as there specified and required.

PROBLEM 37.

Regular heptagonal prism with axis parallel to V and inclined up to the right at 60° from vertical. Front face of prism to be parallel to V. Altitude of prism 4″. Radius of circumscribed circle of base 1¼″.

A heptagonal prism is one whose bases are heptagons, that is, figures having seven sides.

Analysis:—It will be seen by inspection of the object placed as specified, that the drawing can not be commenced with either the top or the side view. Give reason for this (what rule?). The front view shows the exact altitude of the prism, the true length of all the lateral edges, and the true size and shape of the front face. The remaining six faces do not, however, appear in true dimensions, and these dimensions cannot be obtained from the top or side views. Consequently though the front view may be begun it cannot be completed independently.

If, however, some view of the object could be outlined from which the faces could be projected to the front view in their proper foreshortened dimensions, the front view could be completed and after that—also by the aid of the additional view—the top and side views could be completed.

The method of showing the true size of any particular face of an object, as demonstrated in the second part of the preceding problem, will explain how this may be done. The process is, however, reversed. In Problem 36 the main views were completed and from them the fourth view was deduced.

But in this problem the auxiliary view must first be represented as revolved out into the plane of the paper in order that from it the front view may be projected. The problem may readily be illustrated by a model made from wood or cardboard and having a false base of cardboard attached to the lower base of the prism by a small flap along the edge of the false base. In placing the model for study, this flap forming a hinge must be placed in front, that is, towards the observer, in which position the revolution of the auxiliary plane will follow the usual method of revolution of the planes of projection.

Construction:—Draw the circumscribed circle of the base, placing its center as shown in the accompanying diagram, Figure 83.

In proper position outline the heptagon representing the base of the prism.

Since the front face of the prism is to be parallel to **V**, the front edge of the base of the prism must be parallel to **V**.

This does not imply that the basal edge in ques-

tion appears upon the drawing as a vertical line. The pupil should by this time fully realize through study of previous problems that a line may be vertical or horizontal, or of any inclination between, and still be parallel to **V**, if only it lies in a vertical plane.

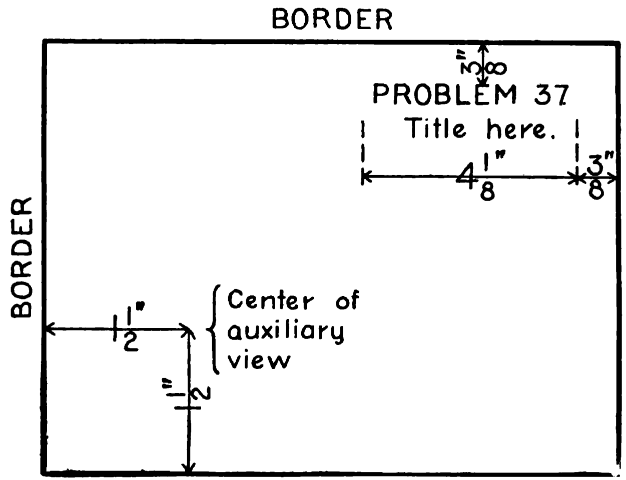


Figure 83.

Since also, an edge is the part of the base nearest **V**, a vertex will be the part of the base farthest from **V**, because the base is a regular figure of an uneven number of sides. By examining the model it will be seen that this vertex, when the base is revolved into the plane of the picture, would lie upon the center line of the front view if that center line were extended.

This fixes the position of the heptagon, and the pupil should therefore begin his construction with the rear vertex of the heptagon placed upon a line so situated that when extended it shall become the center line of the front view.

No geometrical construction need be attempted for making the heptagon. It is most quickly and easily laid out by stepping off seven equal chords on the circumference by means of the hairspring dividers.

Judge as nearly as possible the length of the chord which shall form a side of the heptagon and lay it off seven times upon the circumference. If necessary, reset the dividers to a different length, and lay off as before. Repeat this operation till the circumference has been divided into seven equal parts as required.

It is desired that the pupil shall at once begin the practice of placing views by the use of main lines alone, and without any representation of the planes of projection. Therefore, through the center of the auxiliary view draw a center line, which shall also be a center line for the front view, and upon which the front view may be constructed.

As the axis of the prism is also the center line of the prism, the specification of the problem tells how the center line in question should be placed.

Make this line of indefinite length, say 7 in. or

8 in. Letter it A B, placing A at the left extremity of the line and B at the right extremity. The position of a circle or of any regular figure based upon a circle is determined and indicated upon a mechanical drawing by two lines situated at right angles to each other and passing through the center of the circle. The intersection of these lines fixes the position of the center of the circle, since the intersection of two lines fixes the position of a point, and having this intersection placed and the radius given, it is evident that any circle or figure based upon the circle can be readily determined and drawn. Therefore, through the center of the circumscribed circle of the base just made, draw another and shorter center line at right angles to the one first drawn. Letter its upper extremity C and its lower extremity D. As a matter of practice, the axis of projection between the auxiliary and front planes may be shown. It is, as has already been explained, the line of intersection of the two planes, or the trace of the auxiliary plane upon the main plane. Let it be supposed that the object is 3/16 in. from the vertical plane and equally distant from the auxiliary plane. Decide upon the distance from the fourth view to the trace, also upon the direction which the trace has, then draw the trace of an indefinite length slightly exceeding the width of the auxiliary view. If necessary, in order that these points may be decided upon, represent these planes by two pieces of paper or glass, and place the object in proper position within the angle formed by these planes. Having drawn the trace, place the letters E and F at the point where the center line from the auxiliary view to the front view intersects the trace of the auxiliary plane. Two letters are used in this instance to designate one point on the drawing which is to be regarded—having reference to the opposite sides of the trace—as two views of one and the same point of the object. Therefore the letters should be placed on opposite sides of the trace, each on its own plane. Let E be put on the auxiliary plane and F on the front plane.

Then decide upon the distance between the trace and the front view, and draw the front view, projecting it from the auxiliary view. After completing the outlines of the front view, draw a vertical center line through the center of the front view and extend it across **H**. Mark the lower extremity of this vertical center line G, and the upper extremity H. Also draw a horizontal center line through the center of the front view and extend it across **V**. Mark the left extremity of this horizontal center line J, and the right extremity K. Notice that these directions call for two new center lines, each passing through the center point of the front view of the axis of the prism.

Next draw through the middle of the space between the front view and the upper border, a right and left center line for the top view. Its exact

direction is determined by the specifications of the problem.

Erect projection lines from the front view and upon them lay off each way from the center line of the top view, the proper distances for the width of the top view. These distances can be obtained from the auxiliary view because that shows dimensions at right angles to the dimensions shown in front view.

Referring to the model, let it be supposed that such a plane is passed through it as would be necessary to make the center line of the front view which was first drawn—the center line FB. This plane is supposed to pass entirely through the prism, cutting the front face in the center line of the face and parallel to its long edges.

The plane will also make a line across each base of the prism, and will emerge from the prism along the rear lateral edge. The line made by this plane across the left base is shown in the auxiliary view. It is the one marked A E.

Let it further be supposed that, perpendicular to the plane just described, another plane is passed, also through the axis.

It will cut an upper face and a lower face of the prism, and will also cut lines from the bases at right angles to those made by the first center plane.

These lines will constitute center lines for views at right angles to the views previously drawn; that is, the second plane gives the center lines for the top and side views, and a second center line for the auxiliary view at right angles to the one first drawn. It will thus be seen that the center line in the auxiliary plane at right angles to the one connecting the auxiliary and front views; the right and left center line of the top view; and the vertical center line of the side view; are all made by the same plane, therefore dimensions laid off from this plane (center line) in one view are duplicated in each one of the other views mentioned.

Draw the additional center lines thus described if they have not already been drawn. Designate the second center line of the auxiliary view (already drawn, and situated at right angles to A E) by the letters C and D, placing C at the upper extremity and D at the lower.

Call the right and left center line of the top view L M, L being the left extremity; and call the vertical center line of the side view N O, letting N be the upper extremity. From L M lay off to the front and rear along the proper projection lines from the front view, the correct distances necessary for the width of the top view, obtaining these distances as before stated, from the auxiliary view. Refer to the model, compare with the drawing, and decide whether distances to the right of C D are distances in front of or behind L M. The distances of the various corners of the heptagon from C D give the distances of the corresponding edges from L M. The distance of a point from a plane is measured by the length of a line perpendicular to the

plane and extending to the point, therefore the distance in question must be measured perpendicularly to C D and be laid out perpendicularly to L M.

A convenient means for transferring distances from the auxiliary view to the top view is explained in the following method.

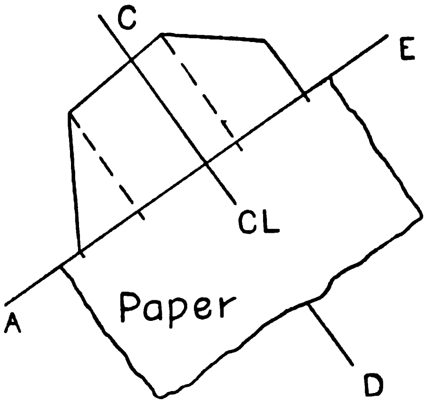


Figure 84.

Project the corners of the heptagon onto the center line A E, as shown in the accompanying diagram, Figure 84. Along this center line place a piece of paper of sufficient size and having at least one straight edge, which edge is to be placed to coincide with A E. On the straight edge of the paper make short lines, the first one being for the center line C D. Mark this first short line C L (meaning center line), as shown in the figure. Next place marks for the left and right extremities of the heptagon; and finally for the intermediate corners of the heptagon as they are projected by perpendiculars upon the center line A E.

Then apply the paper to the center line L M, and from that line mark off to the front and to the rear the distances shown on the paper. Through the points just located draw light lines to the right and left intersecting the corresponding projection lines erected from the front views of the same points.

The intersections so made determine the positions of the corners of the heptagon in top view. The paper may then be applied to the center line of the side view and the corners of the heptagon located there. When submitting the drawing to the inspector for his examination, present also the piece of paper employed in this operation, to be used in testing the drawing and for judging about the pupil's comprehension of the method explained and his understanding of the correspondence of dimensions and positions in auxiliary, top, and side views.

Since the widths of the top view, in front of the right and left center line L M and in the rear of the same, are to be duplicated in the side view by distances to the left and right respectively of the center line N O, the construction already given for the top view will sufficiently explain the method for completing the side view.

The drawing should be finished in the usual man-

ner, except that the projection lines between views are to be inked for a distance of only 3/8 in. from each point projected. Before bringing his drawing to the inspector for the final criticism of the pencil work, the pupil is to erase the projection lines, except the fractional parts mentioned in the preceding sentence. On regular shop working drawings, projection lines are little used and never inked, as they would make the drawings very intricate and confusing. Often they are not drawn at all, but if drawn they are made only in pencil and are erased when the drawing is completed and cleaned. It is desired that the pupil shall gradually dispense with projection lines, and construct his drawings as much as possible from center lines. It is evident that the drawings of many objects, if made full size or to such scale as to convey the desired information, would be of such proportions as to make it impossible to place more than one view on a sheet of convenient dimensions. When the views are on separate drawing boards it is of course impossible to project from any one view to another, and under such circumstances center and base lines must be employed, and reliance placed entirely upon dividers or scale —preferably the latter—for correspondence of dimensions in different views of the same part.

In this problem the auxiliary view may, as far as its shape is concerned, be supposed to represent the base of the prism, or it may be regarded as an end view of the whole prism. But following the plan outlined in the preceding problem, let it be considered a representation of the base of the prism only, in which case it will be a plane merely and therefore will not be shadelined.

PROBLEM 38.

Regular pentagonal pyramid with axis inclined up to the right at 45° from vertical, the apex being higher than the base. Edge of base in front and parallel to V. Radius of circumscribed circle of the base 1½″. Altitude of pyramid 3½″.

Analysis and Construction:—This problem is designed to give further drill on the principles explained in the problem just preceding. The pyramid is not symmetrical with reference to a line bisecting its axis, but the base is a regular figure. Therefore the center lines for the drawing should be shown as passing through the center of the base. The auxiliary view is to be placed as shown in the diagram, Figure 85.

Do not put on the drawing the dimension lines shown in Figure 85 as they form no part of the problem, but are given merely as an aid towards the good appearance of the drawing.

As in the preceding problem, the auxiliary view must have two center lines, situated at right angles to each other. The trace of the auxiliary plane is to be omitted because it is not essential to the construction of the problem, as has been explained, and

it is supposed that the pupil now understands the construction and use of the auxiliary plane.

The three main views are to be placed according to the judgment of the pupil, in their correct positions, and where they will give the sheet an appearance of balance and symmetry.

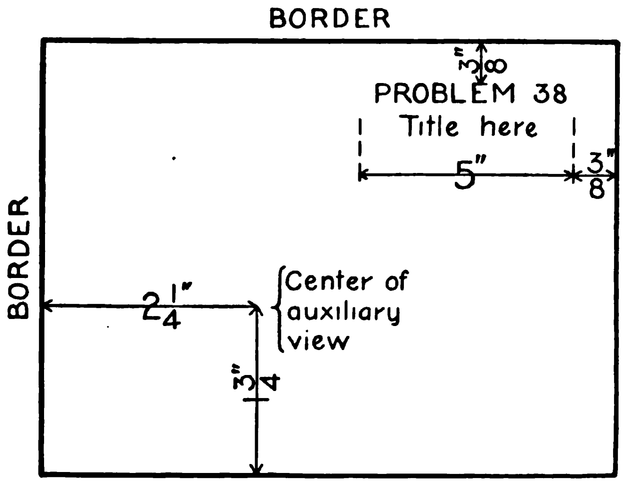


Figure 85.

As soon as the first of the main views is drawn and the center lines of the other two views are placed, the drawing should be submitted to the inspector for approval or suggestions, and for signature.

Finish the drawing in the usual manner, except that the projection lines are not to be inked at all.

PROBLEM 39.

Regular hexagonal prism lying horizontally on a face and having its axis inclined 30° with V, the right hand end being nearest V. Altitude of prism 3½". Edge of base 1⅛".

Analysis:—The pupil is already familiar with the shape of the object to be drawn in this problem, or if not, can easily imagine it. Therefore it is desired that he shall use no model from which to study. When an architect is called upon to design a building, or a mechanical engineer is required to design a machine, it is evident that he must first imagine such design before he can put it upon paper. Of course he may have seen many of the elements of his design in various places, but his grouping and modification of these elements and his introduction of new features, form collectively a new design. It is necessary then for a designer to have good imaginative powers and to be an independent and original thinker. In fact, these qualities are extremely valuable in any occupation. Every pupil in mechanical drawing should cultivate his imagination and independence, by dispensing as much as possible with a model from which to gather ideas.

After a little practice, a model can be read, as it were, and comprehended almost as easily as a book or drawing.

Under such circumstances the pupil is almost copying, and loses a large part of the mental drill

which tends to develop and strengthen his mind and character.

The layout of the drawing for this problem is to be made entirely by the pupils. Review the text and consult the drawing of Problem 32 before going further.

Frequently a draftsman has to place a drawing of some certain dimensions on a paper of limited size, and under any circumstances it is expected that he will economize paper as much as possible. The following directions show the method by which the positions of the different views for a drawing may be placed on the paper to good advantage. First decide upon the number of views, and which particular views are necessary to represent the object in the manner best calculated to convey the desired information. To do this—supposing, of course, that no model or object of like or similar dimensions is to be consulted—first make freehand sketches approximating as nearly as convenient to the desired or proposed dimensions of the object, and in so doing make such views as it is desired to use in the scale drawing. Then estimate approximately the amount of space that each view will occupy on the scale drawing, making due allowance for possible dimension lines and for the spaces between views.

Next calculate from the sketches just made, the positions of the center and other main lines of the views, choose such size of paper as will answer for the work, if that has not already been determined, place the main lines of the views upon the sheet and on them construct the views.

In large drafting rooms, three or four standard sizes of paper are usually employed, and all drawings must be made on one or another of these sizes, the object being to give uniformity to the drawings, thus enabling them to be easily filed away and preserved in drawers of a few standard sizes.

The problems for this course in Projections have all been planned so that the drawings will go on one standard size of paper, therefore in order to place any drawing, the pupil may adopt a method similar to that employed for this drawing and which is given below.

Construction:—Assume the main lines for the view with which the drawing may best be commenced. See Rule 9.

In this case the view first to be drawn, owing to the conditions of the problem, will be the auxiliary view, and the main lines will be two center lines. Their point of intersection must be the center of the auxiliary view, and this point should be away from the borders some distance—say 5/8 in.—more than the radius of the circumscribed circle of base, in order to give clearance between the view and the borders. Through this center just located draw two center lines on which to construct the auxiliary view.

One of these center lines should be extended to connect the auxiliary view with that one of the

main views next to be drawn. Construct the auxiliary view.

Allow some space—in this case $\frac{5}{8}$ in. will suffice—between the auxiliary view and the adjoining main view, and construct the latter.

Determine upon the positions of the center lines or other main lines to connect this main view with the remaining main views, and draw the lines. Decide approximately upon the widths of the spaces necessary for the second and third main views.

Ascertain if there is plenty of room between that one of the main views already drawn, and the borders, for these remaining views. If so, midway of the spaces available, draw the remainder of the center lines necessary to construct the balance of the views, and complete the views. Omit projection lines entirely in this problem.

The amount of room necessary for the specifications, statement, or title of the problem may also be closely approximated. Choose some of the previous problems which have been completed, calculate the size of space in square inches occupied by the title, count the words, and ascertain the average number of words in the title per square inch of space. Count the number of words in the title of Problem 39, and using the average number of words per square inch as just ascertained, determine the area necessary for the title. Lay off this area on the paper as a rectangle of such length and breadth as will best conform to the space available for the title, placing the rectangle at the customary distances from the borders. It is best to make the rectangle a little larger than what the calculation calls for to allow for variations in spacing of letters and words. In this rectangle lay off the usual lines and complete the title.

PROBLEM 40.

Right circular cylinder of $2\frac{3}{8}''$ diameter and $4\frac{3}{4}''$ altitude, having its axes parallel to V, and inclined up to the right at 30° to H.

This problem presents the first instance in which

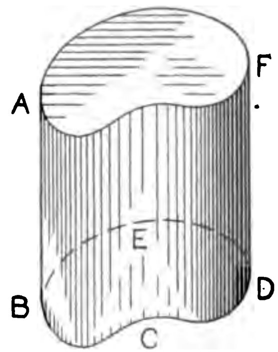


Figure 86.

is required the representation of a solid having a curved surface.

A cylinder is a solid bounded by a cylindrical surface, and two parallel planes which cut all the elements.

A cylindrical surface is a surface of single curvature, and may be supposed to be generated by a straight line A B, Figure 86, moving always parallel to itself and constantly touching a fixed curve B C D E.

The line A B is called the **generatrix,** because by its movement, the surface is generated or created.

The curve B C D E is called the **directrix,** because it fixes or gives direction to the movement of the line A B.

The generatrix in any position of its travel is called an **element** of the surface.

The two plane surfaces of a cylinder are called the **bases,** and the curved surface is called the **lateral surface.** It is evident that the lateral surface may be considered as made up of an infinite number of elements, and the elements are all of equal length.

A right cylinder is one whose elements are perpendicular to its bases.

An oblique cylinder is one whose elements are inclined to its bases.

A circular cylinder is one whose right section is a circle.

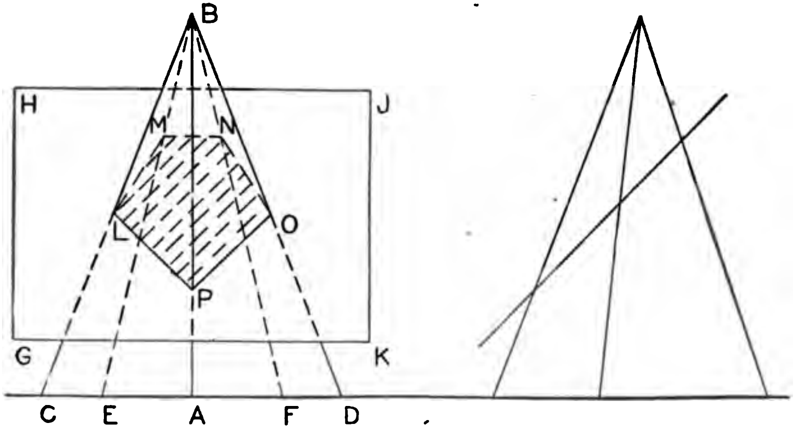


Figure 87.

A section is the figure generated by a plane passing through an object. See Figure 87, in which L M N O P is a section made by plane G H J K cutting the pyramid C B D.

A right section is one made by a plane passed perpendicularly to the axis.

A right circular cylinder can be generated by the

revolution of a rectangle about any one of its sides. See Figure 88, in which the circular cylinder A B E F is generated by the revolution of the rectangle A B C D about its side C D. A cylinder is always supposed to be a right circular unless otherwise specified.

The altitude of a cylinder is the length of the perpendicular between its bases, or its bases produced.

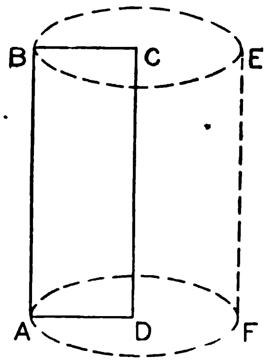


Figure 88.

Analysis:—Upon examination of the model placed as required, it is seen that the front view will be a rectangle, and that the top and side views each consist of two ellipses joined by straight lines.

An ellipse is a foreshortened circle. More exact definitions of an ellipse will be given later.

These ellipses are the representations of the foreshortened circular bases of the cylinder, and are due to the inclination of the cylinder to the planes of projection. The manner of delineating these ellipses according to the rules and methods of Projection is the special feature which it is desired to illustrate in this problem.

If a square and a hexagon were inscribed in a circle it would be evident that a hexagon more nearly approximates the shape of a circle than does a square. If the sides of the square were bisected and a regular octagon were inscribed in the circle, it would more nearly approach the shape of the circle than does a hexagon. It is evident that if the number of sides of the regular inscribed polygon were increased indefinitely, it would approximate more and more closely to the circle, and in fact it may be said that **a circle is a regular polygon of an infinite number of sides.** In a similar way a cylinder may be considered as a regular prism having an infinite number of faces. If so considered its delineation to agree with the specifications of this problem may be made according to the principles laid down in Problems 37 and 39.

An auxiliary view to determine the positions of the faces of the prism was found necessary in beginning Problem 37.

In a similar way, since the cylinder called for in Problem 40 is to be considered as a prism, an auxiliary view to determine the positions of the faces will be necessary. It is not practicable in

drafting to deal with a cylinder as a prism having an infinite number of sides, but a large number of sides may be assumed depending upon the general conditions of the problem, and the approximation thus made is found sufficiently accurate to answer all practical purposes. Any number of sides may be assumed according to the judgment of the draftsman as to the needs of the case.

The corners of the regular inscribed polygon assumed to approximate the circle of the base of cylinder lie in the circumference of the circle and become in the foreshortening views of the object, points of the ellipse representing the base. An ellipse may be considered, like any line, as consisting of an infinite number of points. If a sufficient number of these points are located, they may be joined by means of the irregular curve (scroll) and the ellipse produced.

If too few points are located difficulty will be experienced in so joining these points by means of the irregular curve, as to form a smooth ellipse. If too many points are located, the work is made unnecessarily long and tiresome.

Twenty-four will be found a satisfactory number of sides to assume for the regular prism used to approximate the cylinder in this problem. Pupils sometimes try to lay off the sides of this prism on a view of the side of the cylinder. Inspection of the cylinder held with its curved surface towards the observer, shows that the lateral surface near the extreme or boundary elements is much more sharply inclined to an imaginary projection plane between the object and the observer, than is that part of the surface nearest the plane and the observer. Consequently it is much more foreshortened in projection and any certain portion of the projected view near the boundary elements of the cylinder, represents a greater portion of the object than does an equal space near the center of the view. The faces of the prism should therefore be projected from the regular polygon of a large number of sides assumed as being inscribed in the circle drawn for the auxiliary view.

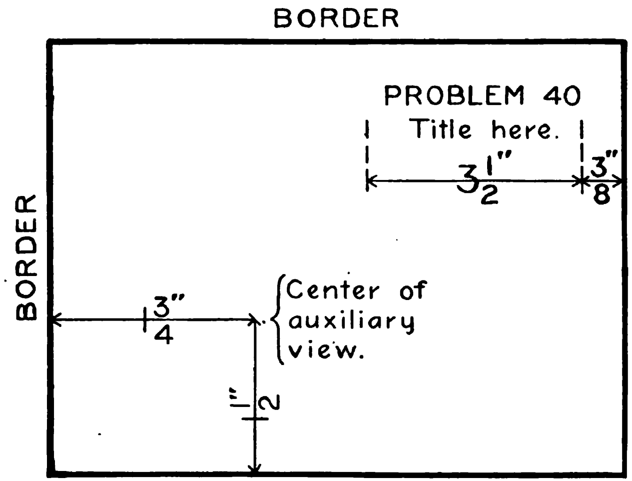


Figure 89.

Notice that the polygon is not to be actually drawn but only its vertices indicated by points laid off at equal distances along the circumference.

Construction:—First draw the auxiliary view, placing its center as shown in the diagram, Figure 89.

Draw its center lines and produce one of them to form a center line for the front view.

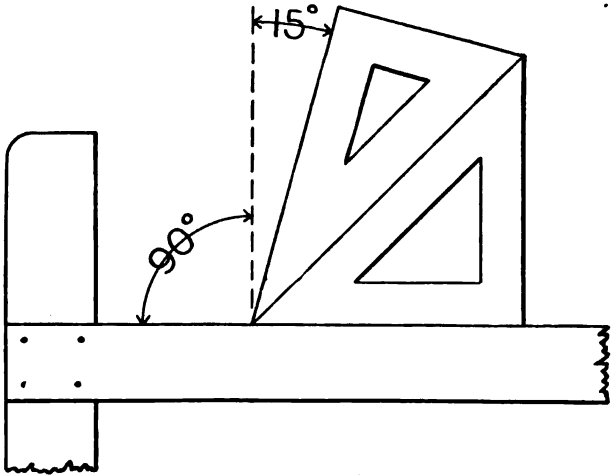


Figure 90.

Divide the circumference of the auxiliary view into equal parts to determine the points which fix the positions of the vertices of the bases and of the elements representing the edges of the supposed regular inscribed prism.

The circumference is already divided into four equal parts by center lines.

The remaining divisions can be laid off in the following manner: Two additional points can be made by use of the T-square alone; two more by use of the T-square and the right angle of a triangle in combination; two more by use of the 60° triangle with the T-square; and two more by use of the 30° triangle with the T-square. The circumference is now divided into twelve equal parts, each being an arc of 30°.

These parts should each be bisected, thus forming the required number of parts—24. The bisections may be accomplished by use of the triangles and T-square. The 45° triangle with the T-square will give four more points. For the remaining points use the T-square and both triangles in various combinations similar to the one shown in Figure 90.

When this has been done the circumference is divided into twenty-four equal arcs of 15° each.

Do not make lines radiating from the center of the view to the circumference as they are not necessary. Also do not make chords joining the vertices of the polygon in the auxiliary view, as they too are not necessary. Simply place points along the circumference.

Draw the complete outline of the front view, and through its center draw center lines for the front and top views, also for the front and side views. Draw the elements of the cylinder representing the

edges of the inscribed prism, projecting them from the auxiliary view.

Notice that the elements do not appear equidistant on the front view, but are nearer together towards the extreme elements of the cylinder owing to the greater foreshortening of the surface at those parts, as explained in the latter part of the Analysis.

Place the remaining center lines for the top view and for the side view. Next lay off the extreme elements in the top and side views, thus giving the widths of those views. Then lay off the remaining elements representing the edges of the approximate prism. The distances of all these elements from the respective center lines of the two views are obtained from the auxiliary view, according to the method explained and shown in Problems 37, 38 and 39.

The lengths of these elements have already been shown in front view and may be projected from there to the top and side views. Connect the ends of the elements in each of these views by means of the irregular curve and form the ellipses representing the bases of the cylinder. The oblique projection and therefore foreshortened view of a circle is an ellipse.

Read carefully the directions on how to use an irregular curve. See article on Use of the Irregular Curve, and Problem 24.

Get the ellipses as smooth and symmetrical as possible.

A symmetrical figure (ellipse or any plane figure) is one which has for each of its points on one side of a given straight line, a corresponding point similarly situated on the other side of the line. In such case a straight line joining the two corresponding points is perpendicular to the given line and is bisected by it.

An ellipse is symmetrical with regard to its long diameter and also with regard to its short diameter.

This will be evident if the ellipse is considered as a foreshortened circle, and the diameters of the ellipse as two diameters of the circle perpendicular to each other. Therefore, when a portion of the irregular curve has been found to match several points of the ellipse, the curve should be reversed and the same part used to draw the three other corresponding parts of the ellipse on the opposite sides of the diameters. There is usually a tendency to make an ellipse too pointed at its ends, due to matching too many points at one time with the irregular curve, and to stopping each portion or quarter of the ellipse at the diameter. Avoid this appearance by finding a curve of small radius on the irregular curve and using it to draw a portion of the ellipse running right across the diameter. In very pointed or small ellipses this small curve may be made with the spring bow instruments.

The two ellipses in either top or side view may be determined by projection, or after one of them has been obtained in either view the remaining one may

be obtained by a different and perhaps shorter method. Since all the elements are of equal length, all points of the upper base are equally distant from the corresponding points of the lower base. Therefore, having outlined an ellipse in one view, set the compasses to the foreshortened length of the elements in that view, and from the points of the first ellipse cut off the elements to be all of equal foreshortened length. Connect their ends and form the second ellipse of that view.

Indicate the way the points are projected from one view to another by light projection lines extending about 3/8 in. from the points.

Elements, where visible, should be inked in as extremely fine—1/200 in. or less—black full lines; where invisible, as extremely fine black dash lines.

The shadelines on this problem are to be determined in the usual manner and will be found to include portions of the curved lines of the ellipses. Place tangent rays of light upon each view to show how it was determined where the shadelines begin and end.

These curved shadelines may be made in ink by shifting the position of the irregular curve a trifle, or by rocking the drawing pen somewhat out of vertical, about the upper edge of the irregular curve as a fulcrum, taking care that the pen does not make a ragged line or bring the ink in contact with the curve, as that would cause a blot. The shaded portion of the curve should be graduated so as to taper off into the ordinary line of the object without showing the place where one stops and the other begins. The auxiliary view representing, as it does, a plane merely, will not be shadelined. When a circle is to be shaded, the line is made in a peculiar manner by springing the leg of the compasses, as will be explained in Problem 54.

The attention of the pupil is called to the following important fact—that by a process similar to the one explained in this problem, any curve or any line however irregular may be portrayed. That is, determine as many points as may be necessary and connect these points to form the line.

Do not use a center line of a circle for a dimension line. When dimension figures must necessarily be placed so as to interfere with any line of the drawing and the character of such line would still be evident if a small portion of the line were removed, as is the case with the elements on this drawing, omit such small part, thus giving a clear field for the dimension and making it show much more clearly.

To do this, draw a light pencil line around the figures and against it, when inking the drawing, stop the lines which would otherwise cross the dimension figures and render them obscure. When the drawing is cleaned, erase the pencil line around the dimension figures, which will then stand out prominently in a clear space.

PROBLEM 41.

Right circular cone having its axis parallel to H and inclined 30° to V. Apex in front and at the right hand. Altitude of cone $4\frac{3}{8}''$. Diameter of base $2\frac{3}{4}''$.

A cone is a solid bounded by a conical surface,

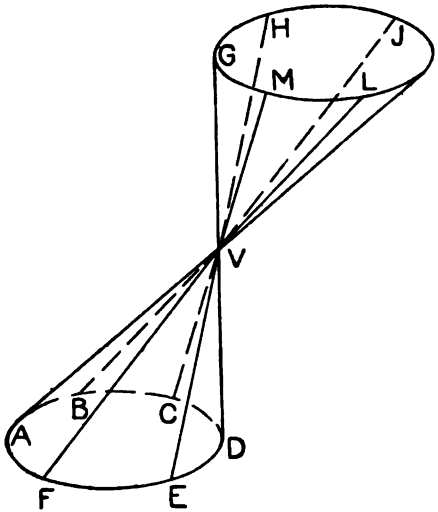


Figure 91.

and by a plane which cuts all the elements. See Figure 91.

A conical surface is the surface generated by a moving straight line called the **generatrix,** passing through a fixed point called the **vertex** or **apex** and constantly touching a fixed curve called the **directrix.**

In Figure 91, A K is the generatrix, V is the vertex, A B C D E F is a directrix, G H J K L M is also a directrix, V—A B C D E F is a cone, and V—G H J K L M is another cone.

The generatrix in any position of its travel is called **an element** of the surface.

If the generatrix is of indefinite length, the conical surface consists of two portions, one above the vertex, and one below, the former being called the **upper nappe** (a word from the French, meaning sheet or surface), and the latter, the **lower nappe.**

Through a given point in a conical surface one element and only one can be drawn.

The conical surface is called the **lateral surface,** and the plane surface is called the **base,** of the cone.

The **axis of a cone** is a right line joining the vertex and the center of the base.

A **right cone** is one whose axis is perpendicular to the base.

A **slant cone** is one whose axis is inclined to the base.

A **right circular cone** is one whose axis is perpendicular to the base and whose base is a circle.

As a right circular cylinder may be regarded as a regular prism having an infinite number of sides, so in a similar manner, a right circular cone may be regarded as a regular pyramid having an infinite number of sides.

A right circular cone is also called a **cone of revolution,** because it may be generated by the revolution of a right triangle about one of its legs as an axis. See Figure 92, in which E—A B C is a right circular cone generated by the revolution of the right triangle E D C about its side E D.

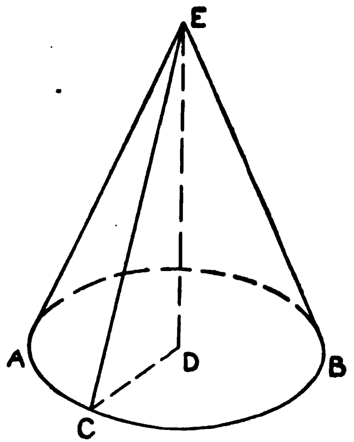


Figure 92.

The hypothenuse of the generating triangle in any position is an element of the surface, and is called **the slant height of a cone.** In Figure 92, E C is the slant height.

Unless otherwise specified, a cone is always supposed to be right circular.

It is evident that the lateral surface of a cone may be considered as made up of an infinite number of elements, but that only in right circular cones are these elements of equal length.

Construction:—Each pupil is to decide upon the method for executing Problem 41, and is also to place the views according to his best judgment. Place that view first to be made, and draw its center lines. Extend one of these sufficiently to become also a center line for the second view, and put in the outline of the second view.

As was the case in Problem 38, the opposite ends of the solid to be drawn are not alike, since one end is a plane and the other a point. Therefore, considered in this way the cone is not symmetrical with respect to the center point of its axis. But the base is a circle, therefore a regular figure, and symmetrical with respect to a line through its center. Consequently a line passing through the center of the base should be used as a center line in drawing the cone.

Having drawn two views, place the center lines for the remaining views, then submit the drawing to the inspector who will suggest, if necessary, how the positions of the views may be improved.

In finishing the drawing, omit the projection lines entirely.

Do not bring every element to the apex of the cone. Let each second element stop a short distance from the apex to avoid a blot at that point.

An excellent drill for the pupil and a good test

of his understanding of this problem and of projection in general, consists in assuming any point on the base of the cone, in the auxiliary view, and finding the corresponding projections of it in the other views.

Any pupil who completes this problem as usually finished, before the expiration of the time assigned for it, is to work out the projections of a point assumed as explained. Note that the point is to lie on the base and therefore within the outline of the base.

PROBLEM 42.

Frustum of a truncated regular pentagonal pyramid having its axis vertical, and its right edge of base parallel to SV. Altitude of pyramid 4½″. Radius of circumscribed circle of base 1⅞″. Pyramid truncated 2⅝″ above the base.

A pyramid, cone or cylinder, is **truncated** when part of it is cut off by a plane intersecting all its elements.

A plane intersecting a solid is called a **section plane** or **cutting plane.**

A frustum is that part of a solid included between the cutting plane and the base of the solid.

Usually and unless otherwise stated, the cutting plane is supposed to be parallel to the base, and it will be so considered in this problem.

The altitude of a frustum is the length of the perpendicular between the planes of its bases.

The slant height of a frustum is the length of the perpendicular between the parallel edges of one of its lateral faces.

Analysis and Construction:—In this and similar problems the solid shown is to be drawn complete in all views before the cutting plane is outlined. It may be necessary in the course of making these views to place **the trace** of the cutting plane, but as before stated, outlining the cut surface is to be deferred till all the views of the entire solid have been completed. If undecided as to which view the cutting plane is first to be shown upon, consult Problem 36, second part, pages 139 and 140; also read the Analysis of the same problem, page 135.

When all the views of the entire object have been completed submit the drawing to the inspector for criticism. After the drawing has been approved and signed by the inspector, continue the work and show the results made by passing the cutting plane and removing a part of the pyramid, thus leaving a frustum. The drawing should be signed again after it is completely penciled and also as usual after it is inked. It will be seen that to follow these directions four signatures by the inspector must appear on the drawing.

The pupil should decide for himself upon the positions of the center and base lines for this problem. Do not separate the views too much. To make sure that the views shall be well placed, calculate the layout of the sheet as explained in Problems 32 and 39.

Having outlined the views, pass the cutting plane if that has not already been done, and find the result.

Put the dimensions showing altitude in the space between the front and side views so that certain dimensions which will be explained later may be properly placed.

As the object is a frustum, the edges of the pyramid are to be erased outside of the cutting plane except for a distance of about $\frac{3}{8}$ in. from the apex in each view. They are left there to indicate the position of the apex and should be finished as dash lines.

The line representing the cutting plane will coincide with the line representing the upper surface of the solid. The position of the cutting plane should be shown, therefore, by producing the trace about $\frac{1}{2}$ in. outside the object. Be careful to represent the plane by the proper kind of a line. See Analysis of Problem 36, also plate of standard lines, Figure 53.

PROBLEM 43.

Development of the surface of the frustum shown in Problem 42.

Analysis:—Development is the unfolding or unrolling of the surface of a solid so that it shall appear as one continuous plane surface.

It is essential also that the faces as developed shall be of such dimensions and so situated with regard to each other, that were the developed surface folded properly, it would produce the form of the solid. Development may be illustrated in the following manner:

Place a sheet of paper upon the drawing board, and lay upon it a right square prism resting upon one of its lateral faces. Draw a pencil line about the prism, then roll the prism over on to a second face, taking care that the edge upon which it revolves does not change position.

Draw the outline of the face on which the prism lies as before. Repeat this operation till each face has been outlined. From its last position turn the prism up on to one of its bases, outline the base, swing the prism back and up onto its other base, and outline the latter. Removing the prism, a figure is seen having a continuous outline, and composed of four rectangles and two squares, each of the same size and shape as the respective face of the prism from which it was drawn.

This figure then is the development of the prism which may be proven by producing from it a facsimile of the original prism. To do this, cut out the figure along its outline. Then with a penknife, lightly score the paper alone the lines representing the edges of the prism, which operation facilitates folding the paper neatly along straight lines and gives sharp edges to the reproduced prism.

The paper may then be folded, care being taken that the scoring shall be on the outside, and a reproduction of the prism appears.

In order that this reproduction may retain its

shape permanently, it is necessary to fasten the faces in position.

This is accomplished by drawing, before the development is cut out, small surfaces along each of the basal edges of the lateral faces of the prism, and one along a lateral edge. The outline of the original figure is therefore enlarged by these additional surfaces which are called **laps.** These laps are not to be shown when the development is a drawing merely, but are to be made only when it is designed to cut out the drawing and fold it up to form the model.

In cutting out the development to form a model, the outline of the laps is to be followed, and the lines between the laps and faces are to be scored. On models of about four inches altitude, which is a convenient size, the laps should be about ¼″ wide.

When the development is folded as before, the laps, having been previously bent over, present themselves as surfaces to which glue may be applied, thus affording a means of holding the lateral faces together, and of fastening the bases to the sides. It will be found that the laps will interfere with each other unless their ends are beveled, and it is best to cut them so that the angle remaining on each one is a little less than one-half the angle of the base at the place where the laps meet. The ordinary ready prepared liquid glue will be found a convenient means for fastening the model together. Very little glue should be used, and that little be evenly distributed to form a thin coating, so that it will dry quickly and the parts adhere without any trouble. Care should be exercised also, that the model is not soiled with surplus glue.

Nice models can be made from cardboard, which should have a surface of some agreeable color. A thin, stiff cardboard known as "ticket stock" or "tough check" should be used for small models, also for large curved surface models, because it bends into shape readily.

If heavy cardboard is used an allowance should be made for its thickness when constructing the model. This allowance is made by scoring just inside the lines drawn between the basal edges of the prism and the adjoining laps, thus shortening those faces about 1/64 in. at each end. The face to which the bases are attached should be scored just outside the lines separating the bases from the face, thus lengthening that lateral face 1/64 in. at each end. The total difference of 1/32 in. at each end of each face allows for the thickness of the cardboard and permits the bases to be nicely folded over without breaking the joint or bend. If cardboard is not at hand for making the models, heavy drawing paper will answer very well. In this course each pupil is expected to make models of at least Problem 42 and Problem 47.

These models are to be made from the usual 10

in. by $13\frac{1}{2}$ in. sheets of drawing paper and that part of the sheet remaining after the development is cut out is to be bound into the portfolio.

The development of the surface of the frustum shown in Problem 42, may be further illustrated by placing a cone upon its side on the table and rolling it about. Observe the apex while the cone is in motion, also the general form of the developed surface.

Decide how the form of the developed surface might be drawn, also what would be the length (not in inches, but in fact and position) of the line necessary to draw the developed surface.

Also experiment with a pyramid and examine its developed surface.

Determine upon the line chiefly necessary to make this development. Do not make a hasty decision on this point, as pupils are frequently mistaken about it.

Construction:—On one of the sheets of the regular drawing paper lay off a point $2\frac{1}{4}$ in. from the upper border and $4\frac{1}{4}$ in. from the right border.

From this point extend a line to the left and parallel to the upper border.

Having determined upon the line chiefly necessary to make the development, and remembering that a development must show each dimension in true size, ascertain from Problem 42 the true length of this line, as it will be the first dimension needed in the drawing of Promlem 43. Do not use the scale to find the length of the line in question, but transfer the distance from Problem 42 to the new sheet—Problem 43—by means of the dividers. Look carefully at this line of the drawing of Problem 42 and see that it shows absolutely a true length as desired, for this is a common point of error.

Lay off this dimension just ascertained, along the line previously drawn. Let the point first placed in the drawing be the right extremity and let it represent the apex. Outline the general form of the developed surface, which being done, proceed to divide it into faces by laying off along this outline, distances and lines corresponding to the length of the basal edges of the pyramid. Connect the points last made with the point representing the apex and the lines resulting will represent the lateral edges of the pyramid.

Next divide the lateral edges into sections corresponding to the parts as shown in Problem 42, and attach the upper and lower bases of the frustum to one of the faces. The bases may be attached to either of the faces, but let them in this drawing be attached to the second one from the line first laid out and upon which the construction was begun. Apply Problem 23 in laying out these bases.

Put dimension lines upon the development, marking the long radius of development, A; the edge of the large base, B; the short radius of development used in dividing the lateral edges into sections, C; and the edge of the small base, D.

Each of these letters is to be placed on the dimen-

sion line as a dimension figure would be placed. These lines are then called **reference dimension lines.** Put a note in the lower right corner of the sheet as follows:

Note:—Dimensions marked A, and B, etc., on this and similar problems are equal respectively to dimensions correspondingly marked on the problems immediately preceding.

Make this note in the standard style of free hand lettering.

Then put reference dimension lines on Problem 42, marking them A, B, C, and D, to agree with Problem 43, as the note on Problem 43 will mean nothing unless this is done.

In bringing Problem 43 to the inspector for examination, bring also Problem 42 and a pair of compasses or dividers.

This is imperative, as it is impossible to test the accuracy of Problem 43 without referring to Problem 42.

The developed surface is to be regarded as one continuous, unbroken plane surface, hence in finishing the problem the outline is to be made in black, using lines of the width ordinarily employed to outline an object, but the lines separating the faces of the pyramid and along which the development is to be folded, should be made in red ink. When this problem is brought to the inspector as being completed in pencil, the lines which are to be finished in red should be so indicated by having placed upon each of them a penciled letter R. These letters are to be erased when the sheet is cleaned after inking. When the problem is submitted to the inspector as being completed in ink, the pupil must also present at the same time Problem 42, with the reference dimension lines A, B, etc., properly placed and inked.

Developments are largely employed in practical manufacturing under the name of "Patterns."

A pattern is anything drawn, cut, or otherwise formed, to be used as a guide in making an object, and serving to determine its exact form and dimensions.

Patterns are used by all manufacturers of sheet metal goods, such as tinware, cornices, etc.

Wearing apparel of cloth and leather, is also shaped from patterns which have been drafted for the purpose.

The term pattern is also applied to solid forms, usually of wood or metal by means of which the moulds are made for casting, but patterns of the solid form obviously do not come under the head of developments.

PROBLEM 44.

Outline of paper cut from this sheet and used for construction of model of solid shown in Problem 42.

Construction:—Place the outline of the development on a new sheet in the same position as directed in the preceding problem. No dimension lines need be shown. Draw laps along one lateral edge and

along the top and bottom basal edges of each face of the frustum, making them about $\frac{1}{4}$ in. wide. Bevel the ends of the laps at an angle a little less than one-half the angle included between the two edges of the base of the object to prevent interference when the paper is folded into position to form the model.

Do not attach the laps to the edges of the bases, because in such position they are not as convenient for gluing the model together as when attached to the lateral faces.

Each pupil should place his name; date of construction of model; and numbers of Problems—Problems 42, 43 and 44,—in this case—on the large base. Draw lines for this lettering and execute it in the standard free hand style. Pencil work is sufficient for this drawing, except the lettering on the base, and the title and border, which must be inked.

Next remove the thumb tacks, take the drawing from the board, turn the board upside down, lay the drawing on the back of the board, with a knife lightly score the lines along which the model is to be folded and then cut out the development along its outline. Using the drawing board in this manner saves marring its face. Be very careful to remove the thumb tacks from the face of the board so that they shall not mar the desk when the board is reversed.

Follow the outline of the development exactly and do not cut the paper beyond the outline more than is necessary, because the sheet is to be bound in the portfolio with the drawings. Fold up the model and glue it together. It is best to fasten the model together along the lateral edge first. LePage's liquid glue will be found convenient for the purpose. Apply a very small amount, so that it may dry rapidly, and do not get any glue on the outside of the model. Present the model and the sheet from which it is cut, to the inspector, who will sign the sheet if the model is satisfactory. Two signatures are all that are necessary for this problem.

Place the sheet in the portfolio with the other drawings.

PROBLEM 45.

Vertical regular hexagonal pyramid with angle of base in front, cut by a plane which is perpendicular to V and inclines from the left downwards at 45° to the base. Altitude $4\frac{3}{8}''$. Edge of base, $1\frac{3}{4}''$. Axis cut 2 3/16″ above the base. Required:—To show by a fourth view of the frustum, the full size of the section; and to find on SV the true length of the lateral edges of the pyramid and frustum.

Analysis and Construction:—For this problem no model is to be used. Draw the three usual main views complete—that is, representing the whole solid—the main lines being placed as shown on the accompanying diagram, Figure 93.

Having completed the outlines of the three main

views, draw a line to represent the cutting plane. Remember that part of it will show as a line of the object and part of it as a trace. See Problem 42. Also Problem 36, as referred to in Problem 42.

Place the center line of the fourth or auxiliary

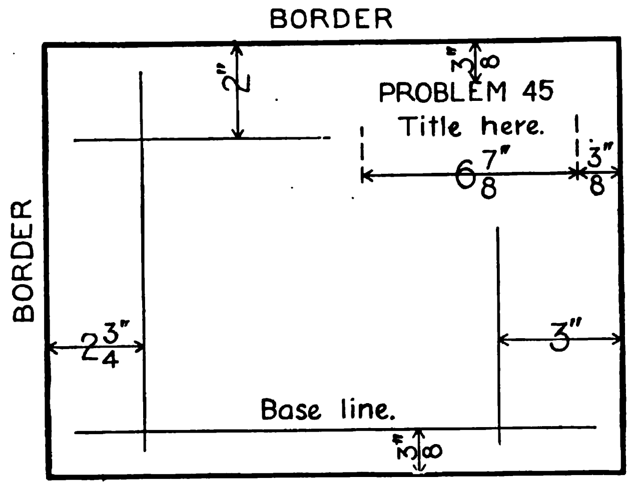


Figure 93.

view $2\frac{1}{4}$ in. from the cutting plane. Draw the auxiliary view, projecting it from the front view in a manner similar to that employed in constructing the auxiliary view in Problem 36. Make this auxiliary view represent at first the complete solid.

Project the apex, then the base, and connect the latter with the former to complete the view. Next show the shape of the figure made by the cutting plane. Carry on the top and side views together. It is desirable to do this in order to determine the front and rear points of the cut face in top view.

In practical work it is always desirable to carry on two or more views at the same time in order to better determine shapes, sizes, and proportions.

The auxiliary view is completed by projection from the front view.

It may be regarded as a side view, differing from the usual side view only in the fact that the point of sight from which the object is viewed, is raised, thereby giving a line of sight (projection line) perpendicular to the cut face, resulting in a full sized view of the cut face or section, and a foreshortened view of the base.

The widths of the auxiliary view will be the same as those of the side view and may be taken from the latter, or from the top view, as the widths of the side view were originally obtained from the top view.

The auxiliary view might also have been drawn by another method, that is, by locating the base and cut face by projection from the front view and measurement from the side view, connecting their vertices to form the lateral edges of the solid and continuing these edges till they intersected, to determine the position of the apex. Of these two methods, the former is the easier, and the latter, if it gives correct results, indicates the more skillful work.

The results obtained by either method should be identical. The better way in the present instance is to employ the method first given.

As the fourth view here represents a solid, it should be shade lined according to rule and thus made to correspond with the main views.

Indicate the position of the apex in each view, including the fourth view, by dash lines about 3/8 in. long.

The second part of this problem requires that the method be shown for finding **the true length of a line** which is oblique to all the planes of projection. This method of finding the true length of a line will be found of value frequently. In this particular case its application becomes necessary in order to lay out the development which constitutes the next problem.

First find the true length of the front left hand lateral edge.

In top view letter the front lateral edge of the pyramid $A_T B_T$, placing A B at the apex. Read the directions for lettering individual points, see Problem 25.

Letter the front left hand lateral edge $A_T C_T$, and the remaining edges in alphabetical order and in right hand rotation.

This will cause the edge whose true length is first required to be designated A C.

Next letter the top view of the cut face. Place the letter H_T at the point where $A_T B_T$ is cut by the plane; J_T where $A_T C_T$ is cut, and so on in a manner to correspond with the way the base was lettered.

Letter the other views of the same points, using the proper subscripts, that for the auxiliary view being A.

Recall Rules 8 and 3. Since A C is not parallel to **SV** it must be made so in order to show full size.

Therefore revolve A C about one of its extremities, A for example, as a center, till it is parallel to **SV**, and find its projections in revolved position.

The side view of this revolved position will be the required full size representation. The revolution of the line A C is graphically performed in the following manner. Place the compasses at A_T as a center and with a radius $A_T C_T$ strike an arc towards B_T, stopping it when the radius (given edge) becomes parallel to **SV**—see Rule 5. Designate the revolved positions of A_T and C_T by using the same letters with the prime mark (′) attached; thus A_T'—which is read A_T prime.

Project the revolved position of the line $A_T C_T$ to the side view. The revolved line as it there appears will show the required full length of the edge (according to Rule 3). Designate the revolved line in side view in a manner similar to that employed in lettering the top view. The revolved positions of the line in front and auxiliary views need not be shown, as they are of no value, because the line as revolved is still oblique to the front and auxiliary

planes, and therefore shows in foreshortened length.

Study the revolved positions of the points A and C. Notice that the point A, since it is the center of revolution, does not change position.

Observe that the point C travels, in revolution, along the circumference of a horizontal circle, which circumference shows therefore in true size and shape on **H** (Rules 1 and 3).

The side view of this circle is a straight horizontal line (Rule 2), and it passes through the original position of the point. The revolved position of C in side view will be on this circumference as far distant from the vertical center line as in top view it is distant from the right and left center line. In a similar manner find the revolved position of J.

$A_S'C_S'$ is the true length of the edge AC, and $J_S'C_S'$ is the true length of that part of the edge AC included between the cutting plane and the base.

Notice that the edge AB shows in true length on **SV** without revolution, because it is parallel to **SV**. Also, AC coincides after revolution with AB, and shows of equal length. This must be correct because all the edges of a regular pyramid are of equal length. Since $A_S'C_S'$ coincides with A_SB_S, the point J_S of the line A_SC_S will be found in revolved position on A_SB_S, and this revolved position might have been found by drawing a horizontal line, (the edge view of a horizontal plane containing the arc of revolution) through J_S till it intersected A_SB_S, the point of intersection being the point required. Using this latter method of the horizontal line, as just explained, find the true length of each of the remaining cut edges of the pyramid, as these lengths will all be needed for the construction of the next problem.

Show the path of revolution of any point both in top view and in side view, as a fine dotted red line.

Show in side view by full red lines, those portions of the revolved edges which project beyond the solid as it naturally appears, after the top part has been removed.

The next problem will be the development of the surface of the solid shown in this problem, and in drafting it the true lengths both of the entire edges and the cut portions will be required. Therefore arrange on this problem for those required lengths by affixing in their proper places, reference dimension lines similar to those placed upon Problem 42 after Problem 43 was laid out.

PROBLEM 46.

Development of the surface of the solid shown in Problem 45.

Construction:—In making a development, the surface of the solid may be supposed to be opened or divided at any desired place, but the natural or most obvious way would seem to be to open it along one of the lateral edges. Either of the edges may be chosen, but for the sake of uniformity in this case let the front left hand edge be chosen. Draw the

faces of the pyramid complete, then along the lateral edges lay off the true lengths of those parts of the edges belonging to the frustum as ascertained in the preceding problem. Connect these points just

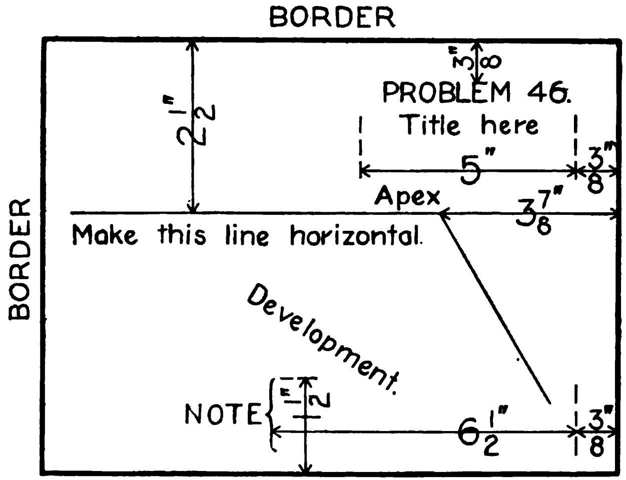


Figure 94.

found and complete the figure by attaching the base and cut faces to the second and third faces from the left of the drawing respectively.

The cut face may be reproduced in this problem as follows: In the auxiliary view of Problem 45, draw at right angles to the center line, a light pencil line to connect those points of the cut face at which the greatest width occurs. Then in Problem 46 lay off a line for the center line of the cut face and across it at right angles draw lines upon which to lay off the widths of the cut face. The position of these lines and the widths to be laid off upon them will be determined by consulting Problem 45.

Join the points so placed and the cut face will be reproduced.

Another method for accomplishing the same results is to divide the cut face in Problem 45 into triangles by imaginary lines, or by light pencil lines drawn from one or two angles of the figure to all the other angles. These triangles may then be reproduced in Problem 46 by using Problem 10, their combined area giving the hexagonal cut face desired.

Test the accuracy of the drawing by ascertaining whether the upper edges of the lateral faces of the frustum agree in length with the corresponding edges of the cut face as seen in auxiliary view and transferred from there to this drawing. They should so agree in length because on the object they are the same lines respectively. Finish this drawing to agree in style with Problem 43, including the "Note" as there explained.

PROBLEM 47.

Oblique pyramid with regular pentagonal horizontal base, having rear right hand edge of base inclined 15° to SV. Front end of this edge to be nearest SV. Edge of base $2\frac{1}{4}''$. Altitude of pyramid $4\frac{1}{2}''$. Axis parallel to V, and inclined up to the right at 15°

from vertical. Pyramid cut by a plane perpendicular to V, inclined up to the left at 60° to the base, and cutting the axis 2⅜″ above the base. Find upon V the true lengths of all lateral edges.

The definition of a slant pyramid will be found under Problem 35.

Analysis:—Since the pyramid is a slant pyramid the lateral edges will be inclined to all the planes of projection. Also according to the specifications, the basal edges are inclined to **V** and **SV**. All the edges, then, are inclined to both **V** and **SV** and their projections on these planes will show the edges in foreshortened length.

Consequently some difficulty may be experienced in starting the drawing. If this be the case, the pupil should refer to Problem 35, reviewing both notes and drawing.

Construction:—Place the front end of the rear right hand edge of the base as shown in the diagram, Figure 95.

Lay off the edge named according to the specifications, and upon it construct the base. Review Problem 23 if necessary. To find how the edge in question may be drawn at the required angle, review Problem 40.

Draw the three main views. Review the definition of "axis," see Problem 32.

The center of the base can be found by drawing lines from each vertex to the middle of the side opposite. They will intersect at the required center.

Pupils frequently make two blunders in this problem which may be avoided by thoroughly understanding what the axis is and carefully studying the position of the axis as specified in the title. Be sure to put the axis on the drawing.

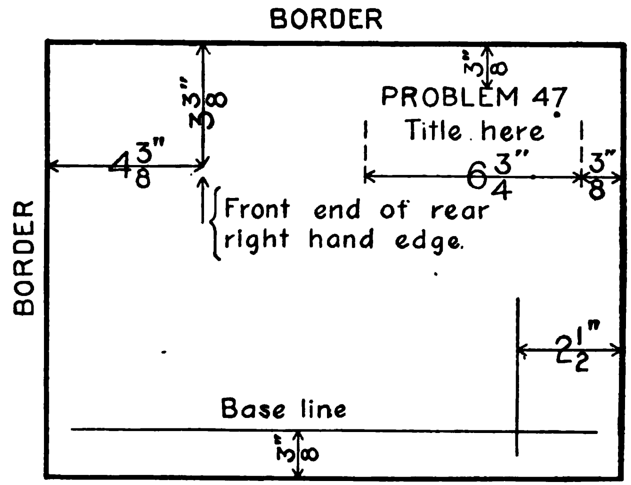


Figure 95.

Do not confuse it with any other line. In determining the length of the axis remember that heights are always vertical distances. Also review the definition of altitude of a pyramid, Problem 32.

Having completed the three main views, pass the cutting plane.

Make no mistake in laying off the height of the

point at which the axis is cut. The word "above" implies a vertical distance.

At a distance of 2⅝ in. from the cutting plane draw the center line for the auxiliary or fourth view of the complete pyramid.

In finding the widths of the base for this view the same method holds good that was used in Problem 45. After the four views of the complete solid have been made and before the surface made by the cutting plane has been outlined, the drawing must be brought to the inspector for his second signature. The problem is to be signed four times.

The surface made by the cutting plane should now be outlined in each view.

In the top view one edge will be found so nearly parallel to the projection line from the front view that their intersection cannot well be determined. The method for finding this required point of intersection should be at once apparent to the pupil, but if not, he may review Problem 45, where a similar question arose.

Show the apex, cutting plane, dimensions—including angles—and shade lines, as in previous problems.

The next problem is a development of the surface of the solid shown in this problem. Therefore the pupil must find the true lengths of all the edges of this solid. There will be found to be five different lengths of lateral edges. These lengths could be determined as in Problem 45, but for the sake of the additional drill given by such variation, let them be found on **V.**

Find first the true lengths of the entire edges and then of the cut portions. Revolve each edge the least distance that is sufficient to answer the purpose for which such revolution is made. Refer to Problem 45 if necessary to review the process of finding the true length of a line by revolving it till it is parallel to the plane on which it is wished to show the true length. Be extremely accurate about all of the work on this problem, and especially in regard to finding these true lengths, because a model will be required, and very slight errors in drawing will distort the development so that a model cannot be made from it.

As this problem is somewhat intricate, the usual reference dimension lines for the development may be omitted to avoid further confusion.

When inking the problem make the true length representation of the edges full red lines. Otherwise finish in the regular style.

PROBLEM 48.

Development of the surface of the solid shown in Problem 47.

Construction:—Use the same placing as that employed in making the drawing of Problem 43.

Let the surface be supposed to be opened along the left or longest edge of the pyramid. Draw the development so that the face nearest the upper border

of the sheet shall represent the left front face of the pyramid as shown in Problem 47.

Laying out the faces of the pyramid in this development will be found to be an application of Problem 10. Attach the base to the second face from the left of the development. Attach the face generated by the cutting plane to the middle face of the development.

On the cut face as shown in full size on Problem 47, draw diagonals in pencil only, or imagine them drawn if that is found sufficient, from each of the two lower vertices to the remaining vertices of the face, thus forming two sets of overlapping triangles. On the development, Problem 48, reproduce the cut face by using these diagonals—again an application of Problem 10. Test the accuracy of the drawing by ascertaining whether the sides of the reproduced cut face are equal respectively in length to the corresponding edges of the cut lateral faces of the pyramid, which they should be.

Since the reference dimension lines were omitted on Problem 47, there will be no occasion to place on this drawing an explanatory note in regard to such lines.

PROBLEM 49.

Outline of the paper cut from this sheet and used for construction of model of the solid shown in Problem 47.

Construction:—This problem is so similar to Problem 44 that almost no explanation for it is needed further than what was given for that problem.

Some of the laps on the upper ends of the lateral faces can not be made full size owing to the position of the cut face. They should be made as nearly the usual size as the outline of the cut face will permit. Be sure to trim the laps sufficiently so that they shall not interfere when the model is glued together. Remember to put draftsman's name, date of construction of model, and the numbers of the problems it represents, on the base of the model before cutting it from the sheet.

PROBLEM 50.

Tin seidlitz powder box $4\frac{1}{4}'' \times 6\frac{1}{4}'' \times 2''$ deep, inside measurements. Cover to lap $\frac{3}{8}''$ over edges of box and to have corners of laps beveled at 45°. Thickness of tin, 1/64″. Required:—Three views, the front view to show the long side.

Construction:—This problem is intended to give practice in making a working drawing preparatory to another working drawing—the next problem—which latter shall show an application of the development of surfaces and the laying out of patterns as used in sheet metal work.

The pupil may use as a model for this problem an ordinary tin seidlitz powder box, such as can be procured of any druggist. Such a box will suffice to show to the pupil the style of box desired, but he is to use the dimensions given in the statement of the

problem. The pupil should remember that a working drawing is one which shows the workman what to make and how to make it.

It must show the shapes of all parts of the object and state their dimensions.

In this problem see that the views are placed so as to give as nearly as possible, equal spaces about the views vertically on the sheet, also equal spaces horizontally on the sheet.

Make the drawing represent the thickness of the tin. This is not really practical and would not be done in a drafting room, because the thickness is very small and the information conveyed by portraying this minute detail is of less value than the time and work expended in making it. But the thickness should be taken into consideration, and its representation here is required as practice for the pupil in doing nice and exact work in drawing and as a slight drill in calculation.

Since the dimensions given are inside dimensions, the dimension lines are best placed on the inside of the outline of the drawing. When a dimension line is placed on what may be termed the inside of the drawing, the drawing frequently looks better if the dimension line is placed more than a quarter of an inch from the line whose dimension it shows. When the lines between which a distance is to be shown, are very close together, the arrow heads should be placed outside the lines, thus leaving clear for the dimension the entire space between the lines, as shown in Figure 96.

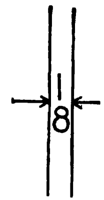


Figure 96.

Other forms used under similar circumstances but where the lines are still closer together are shown in Figure 97.

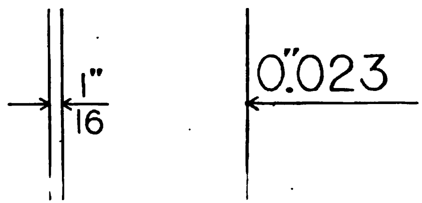


Figure 97.

Produce in red—an extension line—the shorter of the lines between which one of the specified angles of 45° appears, in order to give more room for the figures.

Shade line the drawing as usual.

PROBLEM 51.

Shapes and dimensions of sheet tin necessary to make box and cover shown in Problem 50. Scale, half size.

Construction:—This problem affords an example of a "scale" drawing. The term "scale drawing" is familiarly used in distinction to "natural size" or "full size drawing." See paragraph on Use of the Scale, page 45.

The proportion or scale here specified is "half size" and the drawing should be made to have dimensions actually half the magnitudes specified in the statement of the problem.

Nevertheless the dimension lines when placed upon the drawing should bear figures giving the full-size dimensions. In this way the drawing affords the eye a representation having true proportions, and it lies with the workman to make the object in its true sizes as given by the figures. Study Figure 63 and Figure 64.

Calculate the amount of room the developments will occupy and place them according to the best judgment to look as well as possible.

The dimensions should read from two directions only and should clearly indicate the "working edges" by the absence of the "closing in" dimensions. See Problem 31.

The "over all" dimensions are very important and must not be omitted.

Dimensions should show that due allowance has been made for the thickness of the tin.

Indicate where the tin is folded, by light red lines.

PROBLEM 52.

Iron dripping pan $1\frac{1}{4}''$ deep and $3\frac{1}{2}'' \times 6''$ on the bottom, with sides flaring out at the top at 27° from vertical. Ends fastened to sides by laps on the ends reaching around the sides 15/16″ at the top edge, tapering to 0″ at the bottom and corner of pan. Thickness of iron 3/128″.

Construction:—Instructions upon the protractor, which instrument is to be used in laying out the angle specified in this problem, will be found under the description of tools, and directions on use of tools.

Top and front views only are to be drawn for this problem.

Place the line representing the bottom of the pan in front view, 1 in. away from the lower border, and let its left extremity be $1\frac{5}{8}$ in. from the left border. In top view place the line representing the nearer edge of the bottom $2\frac{7}{8}$ in. from the line representing the bottom in the front view.

Two views are usually all that are required in practical work, for by them all of the dimensions of an object can be shown. If the object is particularly intricate, or the drawing unusually obscure, more views are employed. Three or four views are usu-

ally demanded in each problem of this course for the sake of the additional drill and practice gained.

The thickness of the iron need not be shown on this drawing by double lines but by the method explained in the latter part of Problem 50.

In the next problem will be required the shape of the metal that would be employed in making the pan, that is, the development of the surface of the pan.

The size of the metal required to construct the pan exceeds the size of the bottom of the pan by an amount on each side or end, sufficient to turn up and form the sides of the pan.

The true length of this distance or amount was not laid off directly by use of the scale and it is therefore better transferred to the development by use of the dividers. Also as it was not laid off in inches, it should not be transferred as inches, but the dimensions may be marked by letters.

Adopt this method of using reference dimension letters where a distance is not known or specified in inches, during this course in drawing because the work is chiefly theoretical. For shop use the workman would require to have the dimensions stated in inches and fractions.

Four reference dimension lines are to be placed upon the drawing as follows:—

A, to show the length of the inclined end (also side, as they are equal) of the pan, or as it may perhaps be expressed, the distance between the upper edge and the bottom of the pan;

B, to show the length of the upper edge of the end;

C, to show the length of the upper edge of the side; and

D, to show the true length of the unattached edge of the triangular lap.

The development also requires the determination of the true length of the longer free or unattached edges of the triangular pieces which are parts of the ends of the pan, and which fold around the sides to fasten the ends thereto. This required length should be determined by the method used for finding the true length of a line, see Problems 42, 45, and 47. Use the edge of the front right hand triangular lap in finding this length so that the drawings shall be uniform.

Use the lower end of the line as the center for revolution, and show the true length on the front view.

PROBLEM 53.

Shape and dimensions of iron necessary to make the dripping pan shown in Problem 52.

Construction:—The development is best begun by laying off the shape of the bottom of the pan.

No account is to be taken of the thickness of the iron.

Place the left end of the bottom 3 in. from the left border, and the nearer side of the bottom 2¼ in. from the lower or nearer border. Next lay out the sides and ends of the pan. The bevels of the sides and ends are to be obtained from Problem 52 and are not to be laid off with the protractor.

Lay off the front right hand lap of the pan according to the length obtained for it in Problem 52.

This dimension can also be found directly on the development itself by the following method, which may be called a draftsman's short cut to the end desired. Map out the work of this method at the left of the drawing because the corresponding place at the right is already utilized for the first method. Along the line representing in the development the top edge of the front side of the pan, lay off 15/16 in. from the corner and towards the opposite end of the line. Mark this point E, and from it measure the distance to the point representing the corner of the bottom, which mark F.

The distance E F is the required length of the edge of the lap. Compare it with the length D found by the first method. They should be equal.

Duplicate measurements are to be put upon the development expressing each over all dimension and each lettered reference dimension in both ways—by letters and figures; also by figures alone.

The pupil is to prove the accuracy of his work by constructing a cardboard or stiff drawing paper model of one end of the pan before bringing the drawing to the inspector.

One-half the length of the pan will be sufficient. The model is to be submitted to the inspector, who will affix his signature if the model is satisfactory.

END PART I.

INDEX

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